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WATER SUPPLY AND WATER QUALITY CONTROL STUDY KEYSTONE RESERVOIR ARKANSAS RIVER BASIN, OKLAHOMA

Federal Water Pollution Control Administration
Dallas, Texas

June 1966

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WATER SUPPLY AND WATER QUALITY CONTROL STUDY
KEYSTONE RESERVOIR
ARKANSAS RIVER BASIN, OKLAHOMA

Study of Needs and Value of Storage for Municipal and Industrial Water Supply and Water Quality Control

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UNITED STATES DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Southwest Region
Dallas, Texas

WATER SUPPLY AND WATER QUALITY CONTROL STUDY

KEYSTONE RESERVOIR

ARKANSAS RIVER BASIN, OKLAHOMA

A survey has been made which discloses a future need for municipal and industrial water supplies and a future need for storage for streamflow regulation for the purpose of water quality control. These conclusions are based on results of economic and demographic studies.

Prepared for

DEPARTMENT OF THE ARMY

U.S. Army Engineer District

Tulsa, Oklahoma

UNITED STATES DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
South Central Region
Dallas, Texas

JUNE 1966

TABLE OF CONTENTS

	Page
LIST OF TABLES	iv
LIST OF FIGURES	vi
I. INTRODUCTION	
Request and Authority	I-1
Purpose and Scope	I-2
Acknowledgments	I-2
II. SUMMARY OF FINDINGS AND CONCLUSIONS	
Findings	II-1
Conclusions	II-2
III. PROJECT DESCRIPTION	
Location	III-1
Streamflow	III-2
Water Quality	III-3
IV. STUDY AREA DESCRIPTION	
Location and Boundaries	IV-1
Climate and Geography	IV-1
Principal Communities and Industries	IV-1
V. WATER RESOURCES OF THE STUDY AREA	
General	V-1
Quantity of Water Available	V-1
Quality of Water Available	V-2

TABLE OF CONTENTS (Continued)

		Page
VI.	THE ECONOMY	
	Present	VI-1
	Future	VI-6
VII.	WATER REQUIREMENTS	
	Municipal Water Use	VII-1
	Industrial Water Use	VII-1
	Rural Water Use	VII-4
	Irrigation	VII-4
VIII.	WATER QUALITY CONTROL	
	Municipal, Industrial, and Agricultural Pollution	VIII-1
	Water Quality Objectives	VIII-2
	Waste Loadings	VIII-2
	Flow Regulation	VIII-3
	Annual Draft-on-Storage Needed to Control Water Quality	VIII-4
IX.	WATER SUPPLY AND WATER QUALITY CONTROL PLAN	
	Water Supply	IX-1
	Water Quality Control	IX-3
X.	BENEFITS	
	Municipal and Industrial Water Supply Benefits	X-1
	Costs and Water Supply Benefits	X-1
	Water Quality Control Storage Benefits	X-2

TABLE OF CONTENTS (Continued)

		Page
XI.	BIBLIOGRAPHY.	XI-1
	APPENDIX	
	A. Analysis of Mineral Quality - Keystone Reservoir	A-1
	B. Water Quality Control Needs - Methods of Analysis	B-1
	C. Benefit Calculations.	C-1

LIST OF TABLES

Number	Title	Page
III-1	Principal Features - Keystone Reservoir, Arkansas River Basin.	III-1
III-2	Minimum Monthly Releases - Power Operation Plan, Keystone Reservoir.	III-2
V-1	Municipal Ground Water Supplies in the Study Area.	V-1
V-2	Major Reservoirs in the Vicinity of the Study Area.	V-3
V-3	Chemical Quality Municipal Water Supplies in the Study Area	V-4
V-4	Chemical Character of Surface Water for Selected Points in the Study Area	V-5
VI-1	Population Trends in the Study Area, 1920 - 1960	VI-2
VI-2	Labor Force Distribution in the Study Area. . .	VI-5
VI-3	Population Projections for the Study Area 1980, 2000, 2020, and 2070.	VI-7
VII-1	Study Area Municipal Water Use and Water Supply Data	VII-2
VII-2	Projected 2020 Industrial Water Requirements in the Study Area	VII-3
VIII-1	Annual Draft-on-Storage Needed for Water Quality Control Below Keystone Reservoir. . .	VIII-4
B-1	Monthly Mean Discharge - Arkansas River at Tulsa, Oklahoma	B-2
B-2(A)	Minimum Monthly Streamflow Required for Water Quality Control Below Keystone Reservoir. . .	B-3
B-2(B)	Minimum Monthly Streamflow Required for Water Quality Control Below Keystone Reservoir Present Conditions	B-4
B-3	Supplemental Water Quality Control Requirements Arkansas River Below Keystone Reservoir, 1980, 2000, 2020, and 2070.	B-5

LIST OF TABLES (Continued)

Number	Title	Page
B-4	Plotting Positions in Percent.	B-7
B-5	Annual Draft-on-Storage Needed for Water Quality Control Below Keystone Reservoir . . .	B-8

LIST OF FIGURES

Number	Title	Following Page
III-1	Location Map.	XI-3
III-2	Arkansas River-Tulsa and Vicinity	III-1
VI-1	Population Trends & Projections	VI-8
	APPENDIX	
A-1	Dissolved Solids - Chloride Relationship Arkansas River (Tulsa).	A-2
A-2	Keystone Reservoir Chloride Concentration Duration Curves	A-2
A-3	Keystone Reservoir Dissolved Solids Concentration Duration Curves	A-2
A-4	Dissolved Solids - Stream Discharge Relationship - Arkansas River (Tulsa) . . .	A-2
A-5	Dissolved Solids Concentration Duration Curve - Arkansas River - Tulsa.	A-2
B-1	Annual Draft-on-Storage for Water Quality Control Below Keystone Reservoir. .	B-6

I. INTRODUCTION

Request and Authority

In a letter dated February 18, 1959, the Corps of Engineers, Tulsa District, requested the assistance of the Secretary of the Department of Health, Education, and Welfare in ". . . evaluating low flow regulation benefits attributable to the Keystone project in alleviating downstream pollution and providing supplemental water supply on the Arkansas River." A study was made and a report "Evaluation of River Discharges, Keystone Reservoir, Arkansas River, Oklahoma" was transmitted in December 1959 in accordance with the Water Supply Act of 1958 (Public Law 85-500, Title III), and a Memorandum of Agreement between the Department of the Army and the Department of Health, Education, and Welfare, dated November 4, 1958.

After recent authorization to include hydroelectric power generation in the Keystone Reservoir project, the Corps of Engineers, in a letter dated August 6, 1963, advised the Public Health Service* that . . ."Planning has been initiated for a downstream reregulating structure to smooth out power releases and provide regulated flows at Tulsa. Consideration is being given to including water quality control as a project purpose in accordance with provisions of the Federal Water Pollution Control Act, as amended (33 U.S.C. 466 et. seq.)."

Since the period of evaluation covered in the Public Health Service report of December 1959 did not go beyond the year 1990, estimates were made by the Corps of Engineers (as stated in the letter of August 6, 1963) of the value of water quality control benefits which will accrue with flow regulation after this time. These estimates were based on criteria and concepts of determining the need for water quality control and its benefits used in the study of December 1959. A request was made in the above letter for the Public Health Service to review the estimates of benefits made by the Corps of Engineers and furnish comments on the analysis. It was further requested that the Public Health Service describe the area to be served. In reply to the request by the Corps of Engineers, the Public Health Service, by letter dated August 15, 1963, recommended a restudy of the Keystone Reservoir to evaluate the need for and value of storage in the project for municipal and industrial water supply and water quality control purposes to the year 2070 in accordance with present-day concepts.

*In accordance with the Water Quality Act of 1965 (Public Law 89-234), approved October 2, 1965, the Federal Water Pollution Control Act, as amended (33 U.S.C. 466 et. seq.) is now administered through the Federal Water Pollution Control Administration.

The analysis of benefits from water quality control in this report is based on adequate treatment of wastes at the source as now required by the Federal Water Pollution Control Act. Authorization to proceed with restudy of the Keystone Reservoir as stipulated above was given in a letter from the Corps of Engineers dated August 21, 1963.

Purpose and Scope

The purpose of this study was to determine the need for and value of storage for municipal, industrial, and water quality control purposes, to the year 2070, in that part of the Arkansas River basin which might reasonably be served by Keystone Reservoir.

Acknowledgments

The assistance and cooperation of agencies and individuals who aided in the assembly of data for this report are gratefully acknowledged. Special appreciation is expressed to the following:

Oklahoma Water Resources Board
Oklahoma State Department of Health
Tulsa County - City Health Departments
Tulsa city officials
Representatives of industry in the Tulsa area

II. SUMMARY OF FINDINGS AND CONCLUSIONS

Findings

1. Keystone Reservoir, a multiple-purpose project located on the Arkansas River in northeast Oklahoma, is essentially complete. The reservoir will contain 1,216,000 acre-feet of flood control storage, and 663,000 acre-feet of storage for conservation purposes.

2. The project study area comprises seven counties (Creek, Pawnee, Osage, Tulsa, Okmulgee, Wagoner, and Muskogee), lying adjacent to and downstream from the reservoir, which are expected to exert water demands or affect water quality in the project area.

3. Authorization was recently given to install hydroelectric power facilities at the dam. Planning has now been initiated by the constructing agency to build a downstream re-regulating structure which will smooth out flows from peaking power releases, and provide regulated flows on the Arkansas River below Keystone Reservoir.

4. The major urban center affected by the project is Tulsa, Oklahoma which is located on the Arkansas River about 10 miles below Keystone Dam. Other municipalities in the study area whose populations are in excess of 2,500 include Pawhuska, Hominy, Cleveland, Sapulpa, Drumwright, Bristow, Sand Springs, Broken Arrow, Collinsville, Okmulgee, Henryetta, Wagoner, and Muskogee.

5. The study area population in 1960 was 544,000. Approximately 76 percent or 411,000 were residing in or near urban areas, leaving a rural population of 133,000.

6. Municipal water use and waste production in the study area is largely centered at Tulsa, with smaller but substantial quantities being attributed to the surrounding communities of Sand Springs, Sapulpa, and Broken Arrow, and the cities of Okmulgee and Muskogee in the lower portion of the study area.

7. Total municipal water use in the study area presently averages about 60 million gallons per day (mgd). Reported municipal waste discharges to study area streams in 1962 were 33 mgd, most of which received secondary treatment prior to discharge. The estimated population equivalent (PE) of the above discharges was 135,000.

8. Estimated firm yields of present municipal water supplies in the study area total 211 mgd.

9. Water to be impounded in Keystone Reservoir is presently of poor chemical quality due to excessive amounts of chlorides and dissolved solids. Present concentrations of these substances in waters which will be contained in the reservoir are much higher than the upper limits of the Public Health Service Drinking Water Standards-1962. For the 17-year period of record (see table V-4), chloride and dissolved solid concentrations in the Arkansas River near Tulsa averaged approximately 500 milligrams per liter (mg/l) and 1,200 mg/l, respectively.

Conclusions

1. The study area's population is expected to grow to 1,550,000 by the year 2020 with 1,450,000 residing in urban areas, and 100,000 in rural areas. The population potential for this area by the year 2070 is estimated in the neighborhood of 3,630,000 with urban and rural population of 3,550,000 and 80,000, respectively. Projected municipal water needs of the study area are expected to be 254 mgd in 2020, and 621 mgd in the year 2070.

2. Industrial water requirements will increase principally as the result of use in petrochemical manufacturing, petroleum refining, thermal electric power production, and food and kindred production. Total industrial water requirements (made up largely of cooling water needs) are estimated to be 237 mgd by the year 2020, and 436 mgd by the year 2070.

3. In addition to existing and planned water supplies of the Tulsa area and anticipated uses of the Arkansas River and treated municipal waste discharges for cooling water, a need for storage to provide an additional 311 mgd for municipal and industrial water supply purposes is expected to accrue in the area by the year 2070. This includes an estimated 159 mgd for industrial cooling water uses and 152 mgd for municipal and high quality industrial water needs.

4. If upstream natural and manmade salt pollution can be controlled and adequate storage can be provided, Keystone Reservoir would be the most likely source for supplying this need and would have an annual benefit to municipal and industrial water supply storage estimated

to be $415,000 during the 100-year study period (1970-2070). The anticipated year of first need is 1995. (See Chapter X, "Benefits," and Appendix C, "Benefits Calculations.") Benefits to industrial cooling water storage could accrue with the existing water quality in Keystone Reservoir. As included in the above figures and shown in Appendix C, industrial cooling water storage would have an annual value of $359,000 for the period of study.

5. To prevent nuisance conditions from occurring in the Arkansas River for a distance of about 80 miles below Keystone Reservoir, and maintain dissolved oxygen levels in the stream which will support fish life and make possible recreation and other uses of the stream, there will be a need for an annual draft-on-storage of 220,000 acre-feet per year by the year 2070. In the absence of the project, water quality control storage would be needed by about the year 2000. However, with the project in place, minimum monthly flows that will be maintained under the power operation plan (see table III-3), appear sufficient to assimilate projected adequately treated waste discharges to the stream until the year 2020. After this time, additional storage for regulation of streamflow will be needed if water quality is to be protected in the river below Tulsa.

6. The average annual benefit to water quality control storage in Keystone Reservoir for downstream flow regulation (assuming reallocation of storage when needed for water quality control) is estimated to be $367,000 during the 100-year study period (1970-2070). This is based on the cost of a single-purpose project required to provide the same result, including operation and maintenance, and recognition of a useful project life beyond the period of study.

7. Benefits to water quality control storage in Keystone Reservoir will extend over a considerable length of stream and affect a variety of water uses and are considered to be widespread in scope. Benefits from storage for water quality control will be fully realized only if adequate treatment is provided waste discharged to affected stream reaches.

8. The management of flow releases for quality control should be based on a system for water quality monitoring and streamflow forecasting to assure the most effective use of storage provided.

III. PROJECT DESCRIPTION

Location

The Keystone damsite is located at river mile 538.8 on the Arkansas River about 10 miles upstream from the Tulsa-Sand Springs area in northeastern Oklahoma. (See the Location Map, figure III-1, following page XI-3.) Total drainage area above the project is 74,506 square miles of which an estimated 12,541 square miles is noncontributing. The project is a major unit in the multiple-purpose plan for the development of the Arkansas River basin. It is designed for flood control, navigation, and water supply. Authorization was recently given to install hydroelectric power generation equipment at the dam. Consequently, planning has been initiated by the constructing agency for a downstream reregulating structure to smooth out releases used for power generation and provide regulated flows at Tulsa. (See figure III-2.) Power facilities to be installed at the reservoir will make use of water stored in the reservoir elevations 706 and 723. It is expected that sediment deposits will deplete this storage in about 75 years, after which time Keystone will operate as a run-of-the-river power plant. It is expected that the effectiveness of regulation during drought periods will become progressively less after the year 2015.

Principal features of the reservoir are shown in table III-1.

Table III-1

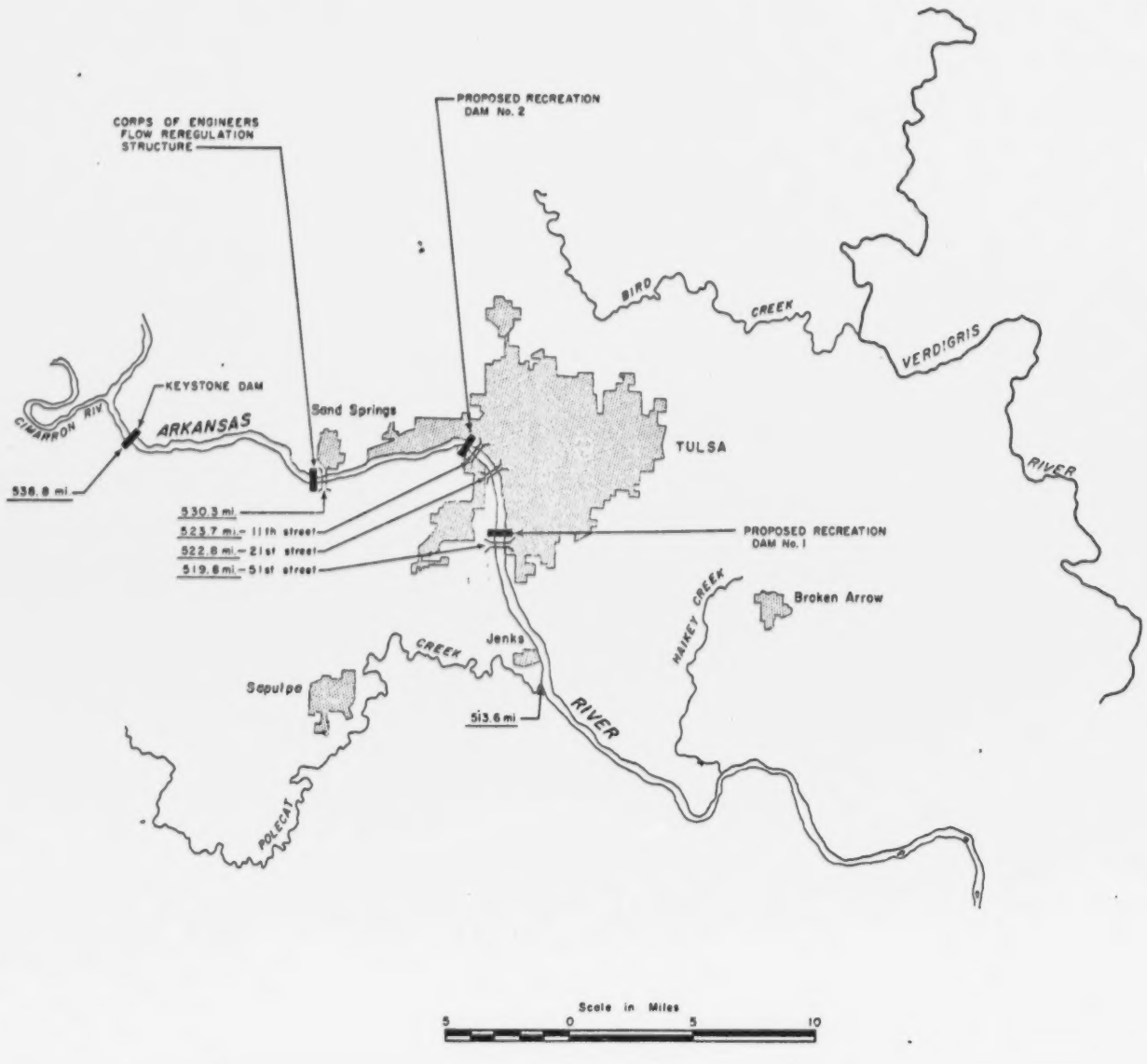
Principal Features - Keystone Reservoir*
Arkansas River Basin

Storage Allocation		
Allocation	Acre-Ft.	Pool Elevations (ft. above MSL)
Flood Control	1,216,000	754.0
Sediment Reserve & Conservation	663,000**	723.0
Total	1,879,000	

* Reservoir statistics are based on the initial plan of operation. Drainage areas will change and reallocations of storage may be made if the recently authorized Kaw Reservoir is constructed.
**Includes 20,000 acre-feet for water supply.

Source: Corps of Engineers

Impoundment of water in Keystone Reservoir began in 1964. Installation of power features is scheduled for completion in late 1967.



WATER SUPPLY & WATER QUALITY CONTROL STUD
KEYSTONE RESERVOIR – ARK. RIVER BASIN–OKLA.

ARKANSAS RIVER–TULSA AND VICINITY

UNITED STATES DEPARTMENT OF THE INTERIOR
federal Water Pollution Control Administration
Date – Jan 15, 1966 DALLAS, TEXAS

FIGURE III–

Streamflow

Since 1926, discharge in the Arkansas River at Tulsa has averaged 6,554 cubic feet per second (cfs). Maximum recorded discharge in the river is 264,000 cfs. A minimum of 27 cfs occurred during the year 1956, the worst drought of record. Discharge records from 1926 to 1964 are available for the Geological Survey gaging station at Tulsa. 1-3/

Streamflow in the study area reach of the Arkansas River, although continuous, fluctuates widely with velocities ranging from moderately fast during periods of high flow to almost sluggish during periods of low flow. Between the Kaw damsite and Keystone Reservoir, the width of the river channel varies from 600 to 2,500 feet, and the banks are from 10 to 15 feet high. Below Keystone Dam, channel widths vary from 600 to 3,000 feet with bank heights of from 10 to 20 feet. The reach of the river within the study area slopes about 2.2 feet per mile. The riverbed is composed of sand, silt, and gravel, and at times shifts fairly rapidly to form bars and split the channel. Channel capacity below the Keystone Reservoir is about 100,000 cfs and increases progressively to about 270,000 cfs near the mouth of the Arkansas River.

Minimum monthly flows that would be maintained under the power operation plan adopted for Keystone Reservoir are shown in table III-2.

Table III-2

Minimum Monthly Releases - Power Operation Plan
Keystone Reservoir

Month	Discharge (Acre-ft.)	Discharge (cfs)	Month	Discharge (Acre-ft.)	Discharge (cfs)
Jan.	31,980	521	July	65,190	1,062
Feb.	30,248	546	Aug.	68,265	1,111
Mar	36,285	591	Sept.	54,145	911
Apr.	41,947	705	Oct.	46,125	752
May	52,276	851	Nov.	34,510	581
June	59,500	1,001	Dec.	32,903	536
			Total	553,373	
				(765 cfs)	

Source: Corps of Engineers 4/

Water Quality

As shown by table V-4, waters flowing into Keystone Reservoir (based upon chemical quality records at Tulsa) are presently of very poor mineral quality. Dissolved solids and chlorides exceed the upper limits of the Public Health Service Drinking Water Standards-1962 5/ by a wide margin. For the 17-year period of record, chloride and dissolved solid concentrations in the Arkansas River near Tulsa averaged approximately 500 mg/1 and 1,200 mg/1, respectively. Waters entering the reservoir are also undeniably hard with total hardness frequently exceeding 400 mg/1 and occasionally 800 mg/1. Sulfate concentrations are within the above limits most of the time.

Investigations are now being made to determine the feasibility of eliminating or reducing both manmade and natural salt pollution in the Arkansas River basin. 6/ As discussed in Appendix A, a major portion of the objectionable minerals entering the study reach of the Arkansas River are attributed to upstream salt pollution.

An analysis of dissolved mineral concentrations expected to exist in the reservoir was made using quality records at Tulsa and reservoir inflow and operation data provided by the Corps of Engineers for the streamflow period 1937 through 1962. 7/ The results are shown graphically on figure A-3 with curve A representing dissolved solids concentrations which might be expected in Keystone Reservoir in the absence of proposed salt pollution abatement and curve B with maximum anticipated control of all identifiable sources above the reservoir. Curves B and C on figure A-2 (taken from the Corps of Engineers Survey Report on Arkansas-Red River Basins, Water Quality Control Study 8/) show the likely occurrence of chloride (Cl^-) concentrations in Keystone Reservoir with and without mineral pollution abatement, while curve A shows the occurrence of chloride concentrations in the river in absence of the project.

IV. STUDY AREA DESCRIPTION

Location and Boundaries

The project study area, shown on figure III-1, encompasses seven counties; Osage, Pawnee, Creek, Tulsa, Okmulgee, Wagoner, and Muskogee in northeast Oklahoma. These counties lie within the Arkansas River basin near the midpoint of the basin and compose the area which can potentially be benefited by the project.

Climate and Geography

The study area enjoys a warm subhumid climate with annual rainfall of about 30 inches and mean monthly temperatures ranging from 37° in January to 83° in July. Geographically, the area is situated in a region of prairie grasslands and cross timbers, and ranges in elevation from 600 to 1,400 feet above mean sea level. The study area portion of the Arkansas River basin is relatively free of natural mineral deposits, however vast areas of the river basin above the study area are underlain by natural salt deposits which contribute to mineral pollution entering the study area.

Principal Communities and Industries

Essentially, the study area is rural in character except in and around the cities of Tulsa and Muskogee.

Industry in the study area is largely oriented around the production and processing of petroleum products, metal fabrication and plating, chemical manufacturing, meatpacking, and agriculture. Principal agricultural activities in the study area include the production of cash grain, cotton, livestock, and dairy products.

V. WATER RESOURCES OF THE STUDY AREA

General

Because of excessively high mineral concentrations, particularly salts, the use of surface water in the study area has been limited to tributary impoundments largely in the Verdigris and Grand (Neosho) Rivers tributary systems. Reservoirs on these streams (which are tributary to the Arkansas River near the lower end of the study area) provide the principal source of water supply for study area communities. Ground water use in the study area is slight.

Quantity of Water Available

Ground Water

Ground water deposits, although significant, are not widespread in the study area. Principal aquifers include the alluvial deposits of the Arkansas River and a narrow belt of sandstone covering the western half of Creek County, the eastern half of Pawnee County, and the south-central portion of Osage County. Ground water yields from wells in these areas range from 50 to 500 gallons per minute (gpm). Well yields throughout the remainder ot the study area are generally less than 50 gpm. No estimates are available on the quantity of water in storage or the potential yields of the above aquifers.

A summary of existing municipal ground water supplies in the study area is shown in table V-1.

Table V-1

Municipal Ground Water Supplies in the Study Area

County	Municipality Served	No. Wells	Yield (mgd)
Creek	Drumright	10	1.5
	Bristow	19	2.9 a/
Tulsa	Broken Arrow	10	1.5

a/ Estimate.

Source: Public Health Service 9/

Surface Water

Prior to the construction of Keystone Reservoir, streamflow in the Arkansas River at Tulsa fluxuated widely as indicated in Chapter III. With exception of the 109 square miles of intervening area, flows at Tulsa are now completely regulated. Minumum flows or regulated power releases are shown in table III-3.

Five other major reservoirs are located within close proximity of the study area. The storage capacities and principal uses for each project are shown in table V-2.

An additional five reservoirs with an estimated total yield from conservation storage of about 300 mgd have been authorized for construction in the study area. 10-13/ These include the Kaw Reservoir on the Arkansas River near Ponca City, and four smaller reservoirs; Candy, Birch, and Skiatook on tributaries to Bird Creek, and Sand Reservoir on a tributary to Caney River. (See figure III-1)

Quality of Water Available

A summary of the chemical quality of study area municipal surface and ground water supplies is shown in table V-3.

The chemical character of surface waters for selected points in the study area is given in table V-4. As shown by the table, high mineral concentrations are found in the Arkansas River at Tulsa. Investigation of chemical quality upstream from this point shows much of the mineral pollution entering Keystone Reservoir to be chlorides contributed by the Cimarron River. A wide range in dissolved solids is indicated at the Ralston sampling station, however, water in the main stem of the Arkansas River upstream from Keystone Reservoir might generally be considered of marginal mineral quality.

Much better chemical quality is found in streams to the east of the Arkansas River, particularly in the Grand (Neosho) River and the Illinois River.

Table V-2

Major Reservoirs in the Vicinity of the Study Area a/

Reservoir	Location	Total Storage Capacity (1000 ac.-ft.)	Principal Uses	Estimated Dependable Water Supply Yield (mgd)
Hulah	Caney River	292.5	Flood Control, Conservation	17
Oologah	Verdigris River	1,020.0 b/	Flood Control, Hydroelectric Power Generation, Navigation, Conservation	39 b,c/
Fort Gibson d/	Grand (Neosho) River	1,287.0	Flood Control, Hydroelectric Power Generation, Conservation	50
Markham Ferry d/	Grand (Neosho) River	444.5	Flood Control, Hydroelectric Power Generation	--
Eufaula	Canadian River	3,848	Flood Control, Navigation, Hydroelectric Power Generation, Sediment Control	50 e/

a/ Completed or under construction.
b/ Initial plan.
c/ Under long-range plans of the Corps of Engineers, the yield may be expanded.
d/ Part of a reservoir system in the lower Grand (Neosho) River.
e/ Available for water supply if the need develops.

Source: Corps of Engineers

Table V-3

Chemical Quality Municipal Water Supplies in the Study Area a/

Municipality	Date	Source of Supply	pH	Chemical Concentrations (mg/l) Chloride	Sulfate	Total Hardness	Dissolved Solids
Tulsa	5-26-51	Lake Spavinaw (Spavinaw Creek)	7.7	5.8	6.1	91	114
Sapulpa	5-15-51	Rock Creek	7.5	31	50	98	181
Muskogee	10-29-51	Grand (Neosho) River	7.7	8	42	120	180
Sand Springs	9- 1-50	Shell Creek Lake	--	22	22	56	117
Broken Arrow	9- 5-51	3 Springs	6.5	8.5	4.9	41	119
Pawhuska	8- 8-50	Lake Pawhuska	--	5.8	13	133	156
Drumright	7-25-50	7 Wells (Composite of Wells 1-5)	--	8.2	63	208	300
Bristow	7-24-51	13 Wells (Sample Well #1)	7.3	54	44	314	457
Wagoner	8- 8-52	Wagoner Lake	7.6	12	54	164	221
Okmulgee	11-29-51	Lake Okmulgee	7.5	56	12	63	166
Henryetta	5- 2-51	Lake Henryetta	8.2	7.5	39	67	99
Collinsville	7-10-52	Caney River	7.6	122	38	280	538
Cleveland	8- 7-50	Lake Cleveland	--	9.0	9.2	68	164
Hominy	8- 9-50	Hominy Municipal Lake	--	7.2	8.2	116	154

a/ Raw water samples.

Source: Oklahoma Planning and Resources Board 14/

Table V-4

Chemical Character of Surface Waters
for Selected Points in the Study Area
(mg/l)

		Dissolved Solids	Chlorides (Cl^-)	Sulfates (SO_4)
ARKANSAS RIVER at RALSTON				
Period of Record: Jan. 1950 to Sept. 1959	Weighted Average[1]	709	244	112
	Maximum[2]	2,520	1,210	353
Jul. 1960 to Sept. 1962	Minimum[2]	322	98	36
CIMARRON RIVER at PERKINS				
Period of Record: Oct. 1952 to Sept. 1959		2,200	1,042	208
		12,600	6,770	750
Jul. 1960 to Sept. 1962		565	212	53
ARKANSAS RIVER near TULSA				
Period of Record: Oct. 1946 to Sept. 1949		1,220	491	141
		5,650	2,910	415
Jan. 1950 to Sept. 1959		521	189	51
Jul. 1960 to Sept. 1962				
VERDIGRIS RIVER near INOLA (adjacent from Tulsa)				
Period of Record: Oct. 1947 to Sept. 1959		247	56	25
		2,480	1,290	103
Jul. 1960 to Sept. 1962		100	18	10
GRAND (NEOSHO) RIVER below FT. GIBSON RESERVOIR (near Dam)				
Period of Record: Oct. 1951 to Sept. 1959		180	11	39
		238	23	57
Oct. 1961 to Sept. 1962		128	1	21
ILLINOIS RIVER below TENKILLER FERRY RESERVOIR (near Dam)				
Period of Record: Sept. 1944 to Dec. 1944		107	9	7
		158	91	55
Oct. 1947 to Sept. 1948		58	2	3
Oct. 1953 to Sept. 1959				
Oct. 1961 to Sept. 1962				

[1] Adjusted to discharge.
[2] Monthly average concentration adjusted to discharge.

Source: Public Health Service, [15] [18] Geological Survey, [16] and Oklahoma Water Resources Board [17]

VI. THE ECONOMY

Anticipated economic and demographic growth is a major factor in determining municipal and industrial water supply and water quality control development needed to meet future requirements. The economic and demographic data presented herein serve as a basis for estimating future municipal and industrial water use requirements and waste loadings in the study area.

Present

Economic Geography

The study area comprises an area of seven counties, including the Tulsa Standard Metropolitan Statistical Area (SMSA), and lies in the region best described as the northeastern Oklahoma-Arkansas River area. This region, the center of one of the Nation's largest oil fields, is already an important industrial area with manufacturing, mining, and agriculture providing the general impetus for present growth.

Tulsa, the principal population center of the area, had a 1960 population (including urban fringe areas) of approximately 300,000, which accounts for about 73 percent of the study area urban population (411,359 in 1960) and 55 percent of the area's total population (544,342 in 1960). Other major population centers in the study area include the towns of Muskogee, Okmulgee, and Sapulpa with 1960 populations of 38,059, 15,951, and 14,282, respectively. (See table VI-1.)

Table VI-1

Population Trends in the Study Area
1920 - 1960

	1920	1930	1940	1950	1960
Osage County	36,536	47,334	41,502	33,071	32,441
Pawhuska	6,414	5,931	5,443	5,331	5,414
Hominy	2,875	3,485	3,267	2,702	2,866
Tulsa					3,414
Pawnee County	19,126	19,882	17,395	13,616	10,884
Cleveland	2,717	2,959	2,510	2,464	2,519
Creek County	62,480	64,115	55,503	43,143	40,495
Sapulpa	11,634	10,533	12,249	13,031	14,282
Drumright	6,460	4,972	4,303	5,028	4,029
Bristow	3,460	6,619	6,050	5,400	4,795
Tulsa County	109,023	187,574	192,363	251,686	346,038
Tulsa	72,075	141,258	142,157	182,740	258,271
Sand Springs	4,076	6,674	6,137	6,994	7,754
Broken Arrow	2,086	1,964	2,074	3,262	5,928
Collinsville	3,801	2,249	1,927	2,011	2,526
Okmulgee County	55,072	56,558	50,101	44,561	36,945
Okmulgee	17,430	17,097	16,051	18,317	15,951
Henryetta	5,889	7,694	6,905	7,987	6,551
Wagoner County	21,371	22,428	21,642	16,741	15,673
Wagoner	3,436	2,994	3,535	4,395	4,469
Muskogee County	61,710	66,424	65,914	65,573	61,866
Muskogee	30,277	32,026	32,332	37,289	38,059
TOTAL	365,318	464,315	444,420	468,391	544,342
Urban[a]/	161,659	244,804	243,681	311,914	411,359
Rural	203,659	219,511	200,739	156,477	132,983

a/ As defined by the Bureau of the Census

Source: Bureau of the Census 19 20/

Portions of the study area are within a hundred mile radius of several major population centers and economic trade areas, including Oklahoma City, Wichita, Kansas, and Fort Smith, Arkansas. The combined population of the SMSA's for these three cities in 1960 was in the neighborhood of one million people.

Resources Within the Area

As exists throughout much of the southwest, the study area is well endowed with resources vital to future growth. As mentioned earlier, the study area is encompassed by one of the Nation's largest oilfields. Much of the past growth is attributed to the petroleum industry. This influence will continue for many years, though to a lessor extent as local oil and gas reserves are exhausted.

In terms of mineral resources, the study area contains ample supplies of petroleum, natural gas liquids, natural gas, clays, stone, and sand and gravel. The combined value of all study area mineral production in 1961 was $129.5 million. 21/

For many American's there is an expressed, though not measurable, preference for life in a region where the climate and natural features of the land encourage outdoor recreation and an informal life. This can be found in the study area. Numerous streams and several large nearby reservoirs are available to study area residents for outdoor, water-oriented recreation. With a prevailing warm subhumid climate these features can be enjoyed the year round. To the immediate east and southeast of the study area are forest and mountainous areas which offer opportunities for camping and hunting, and other leisure activities. As one of the most recent frontier areas of the Nation, the study area is surrounded with items of historic interest.

Transportation will not be a limiting factor as the area grows. The study area is now served by 5 railroads, 2 major bus lines, 14 airlines, numerous motor freight lines, and 7 national highways, including one in the national interstate system. Another interstate highway system through the study area is planned. Barge transportation up the Arkansas River system to the vicinity of Tulsa is now drawing near to reality and will provide an economical means of transportation for bulk commodities from the study area to many of the Nation's distant population centers.

Due to the proximity of oil and gas reserves in the area, the presence of local refineries and the large network of oil and gas

transmission lines now connecting the study area with more distant petroleum reserves, fuel supplies in the study area should be abundant and reasonably priced for years to come. Coal of excellent quality from nearby (southeastern Oklahoma) mines is also available.

The forming of a strong and diversified labor force in the study area is reflected in employment trends over the past 20 years. As shown by table VI-2, study area manufacturing employment more than doubled between 1940 and 1960 with a shift of emphasis from resource-oriented to nonresource-oriented manufacturing.

For the same period substantial gains also occurred in service industries while agricultural employment dropped over 72 percent.

Though still important to the overall economy, (as evidenced by the sale of $43.7 million of farm products in 1959), agriculture has only a minor roll as a means of livelihood in the study area. 22/ Study area agricultural employment in 1960 was only slightly over 3 percent of the total labor force.

Cash grain, livestock, and dairy products are the hardcore of the agricultural economy in the study area. In 1959 a total of 2,233 acres was irrigated in the study area. 23/

Manufacturing

For the most part of its existence, manufacturing in the study area has been oriented toward the petroleum industry. Since the discovery of oil in the study area around the turn of the century, many manufacturing establishments have located in the area to meet the demanding needs of this industry. Along with the work of drilling and tending oil wells and of shipping oil have come the tasks of manufacturing and distributing oil well equipment and supplies, oil refining, petrochemical production, and of exploration for new deposits.

In recent years, however, other manufacturing industries have started to grow in the study area and with the established petroleum manufacturing complex, a strong diversified manufacturing industry is forming. As shown in table VI-2, employment in nonresource-oriented manufacturing increased over fourfold between 1940 and 1960 compared to a 62 percent increase in other manufacturing.

A large aircraft manufacturing plant is now located at Tulsa. Also one of the Nation's largest airlines has established its maintenance headquarters there. In addition, the city has a textile mill, a steel plant (with blast furnaces, coke ovens, and rolling and finishing mills), a steel foundry, and several iron foundries.

Table VI-2

Labor Force Distribution in the Study Area
(1940, 1950, and 1960)

	1940		1950		1960	
	Number	Percent	Number	Percent	Number	Percent
Total Labor Force	163,380	100.0	175,215	100.0	201,615	100.0
Agriculture, Forestry, & Fisheries	24,645	15.1	15,867	9.1	6,707	3.4
Mining	11,519	7.1	10,245	5.8	10,026	5.0
Manufacturing	16,082	9.8	27,226	15.5	37,973	18.8
Resource Oriented	11,309	6.9	17,305	9.9	18,368	9.1
Furn. Lumber, Wood	429	0.3	705	0.4	461	0.2
Primary Metals	2,316	1.4	2,264	1.3	1,803	0.9
Food & Kindred	2,197	1.3	2,687	1.5	3,851	1.9
Chemical & Allied	352	0.2	665	0.4	1,051	0.5
Stone, Clay, Glass & Other Durables	1,530	0.9	4,042	2.3	5,489	2.7
Other Nondurables	4,485	2.8	6,942	4.0	5,713	2.9
Nonresource Oriented	4,773	2.9	9,921	5.7	19,605	9.7
Fab. Metals, Machinery & Trans. Equipment	2,121	1.3	6,090	3.5	14,999	7.4
Textiles & Apparel	937	0.6	1,576	0.9	1,573	0.8
Printing & Publishing	1,715	1.0	2,255	1.3	3,033	1.5
Total Extractive & Manufacturing	52,246	32.0	53,338	30.4	54,706	27.2
Service	90,329	55.3	114,345	65.3	137,388	68.1
Unemployed	20,805	12.7	7,532	4.3	9,521	4.7

Source: Bureau of the Census 24 25/

In the smaller communities of Muskogee, Sapulpa, and Okmulgee, glass industries have become prominent. Dairying is also well developed, particularly in areas east of Tulsa and around Muskogee.

In the creation of wealth and employment, manufacturing is one of the most conspicuous features of the study area economy. Total value added by study area manufacturing production in 1958 was over $292 million. 26/

Several industries which could grow into large water-using industries are present in the study area. In addition to the petroleum industry, these include natural gas processing, petrochemicals (an outgrowth of the petroleum and natural gas by-products industries), and food and kindred products.

Other Industries in the Area

The strong influence of the petroleum industry on study area employment is also prevalent in the nonbasic or service industries. Because the exploitation of the mid-continent oil resources began here, the study area is a center for major business offices and research laboratories for the petroleum industry.

Government employment and government contracts are also important to the study area economy. Formerly a part of the Cherokee, Creek, and Choctaw Indian Reservations, the study area contains the central administering offices for the affairs of the five civilized tribes.

Future

Manufacturing presently plays a leading role in the study area's economy. The rapid growth experienced by manufacturing industries in the past is expected to continue in the future. Completion of the Arkansas River navigation project will provide even greater impetus for growth. Many new industries will move into the area and take advantage of low-cost barge transportation for bringing in raw materials or shipping out bulk commodities.

Principal large water-using manufacturing industries which are expected to grow in the area are petroleum refining, and petrochemicals. Extraction of crude petroleum, natural gas, and natural gas liquids (minerals which are important as raw materials or feedstock in the petroleum and petrochemical products industries) is expected to decline. However, in view of the Nation's increasing demands for fuels and petrochemical products, it is expected that the study area will continue as an important supplier of these commodities. As current petroleum and natural gas resources in the

area become exhausted or insufficient to meet the expanding needs of industry, new supplies are expected to be brought in either by pipeline or barge to compliment increasing needs for petroleum raw materials.

In line with national projections, 27/ petroleum refining in the study area is expected to increase for another 50 to 60 years to meet the Nation's growing need for fuels and petroleum products. Accompanying this is an expected increase in refining capacity from approximately 124,000 barrels per day in 1960 to about 375,000 barrels per day by the year 2020.

The area also appears favorably situated for growth of the rapidly expanding petrochemical industry. Feedstock for this industry could be supplied by existing and future petroleum refineries and natural gas processing plants in this area. The large network of natural gas pipelines currently traversing the general region encompassing the study area is also a source of petrochemical feedstock. Study area and neighboring population centers will provide an important local market for the many products this industry produces. As mentioned earlier, barge transportation will provide the study area with an economical means of transporting bulk commodities to the more distant population centers. The greatest potential for growth of this industry in the study area, however, appears to lie in the production of agriculture fertilizers for the highly productive farm lands in Kansas and northwestern Oklahoma. As indicated in previous studies, 28/ the area is expected to become an important supplier of petrochemicals in future year. Projected 2020 production of these commodities in the study area is 3,320 tons per day.

Because several potentially large water-using industries are present in the study area and the location of another is expected, the future growth of these industries was given special consideration. In addition to the petroleum refining and petrochemical industries mentioned above, substantial water needs are likely to accrue in the food and kindred, and thermal power generation industries.

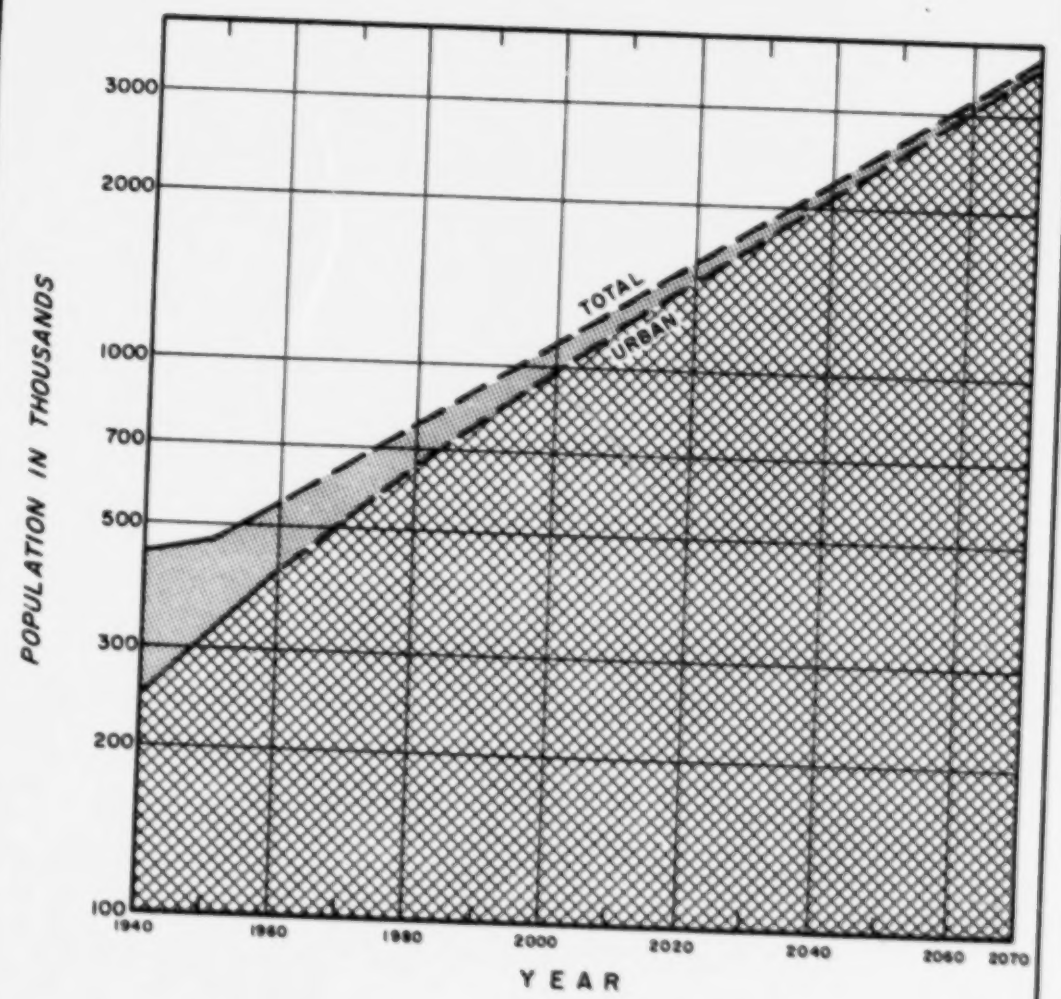
As shown by table VI-1 the population of the study area has experienced a steady growth over the past 40 years. The economic potential of the area indicates a continuation of this trend.

A summary of projected study area population for the years 1980, 2000, 2020, and 2070 is presented in table VI-3 and shown on figure VI-1.

Table VI-3

Population Projections for the Study Area
1980, 2000, 2020, and 2070

Year	Population		
	Urban	Rural	Total
1980	650,000	120,000	770,000
2000	990,000	110,000	1,100,000
2020	1,450,000	100,000	1,550,000
2070	3,550,000	80,000	3,630,000



WATER SUPPLY & WATER QUALITY CONTROL STUDY
KEYSTONE RESERVOIR – ARK. RIVER BASIN–OKLA.

POPULATION TRENDS & PROJECTIONS

UNITED STATES DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Date -- Jan. 15, 1968 DALLAS, TEXAS

FIGURE VI-1

VII. WATER REQUIREMENTS

Municipal Water Use

Municipal water uses include residential, public, commercial, and those industrial uses which are served by organized public water supply systems and are reflected in per capita water use.

Included in per capita quantities are losses in the distribution systems and treatment plants. Present per capita water use in the study area is 140 gallons per capita per day (gpcd) with total municipal water use averaging about 60 mgd. 9/ See table VII-1.

Future municipal water requirements are calculated by multiplying the estimated 2020 per capita use by the projected study area population served by public water supply systems. It is anticipated that within the next 50 to 60 years, the maximum average annual per capita water use in the study area will reach 175 gallons per day and remain near that level thereafter. This is indicated from a study of water use trends in the Arkansas and Red River basins. 28/ Projected municipal water requirements of the study area are expected to be 254 mgd in 2020 and 621 mgd in the year 2070.

Industrial Water Use

Industrial water requirements are those significant quantities of water required in the manufacture of goods and the processing of materials more appropriately measured in use per unit(s) of production. These demands for water supply are exerted by the principal water-using industries described in Senate Select Committee Print No. 8. 29/

Within the study area, four such industrial classes to which significant water demands may be attributed are represented. They are thermal power generation, petroleum refining, chemical (petrochemical) production, and food and kindred production.

Total study area water use by these industries is expected to reach 237 mgd by the year 2020. This estimate is based on levels of production and unit water needs determined in the Public Health Service study mentioned earlier. 28/ Figures used in computing water requirements are shown by industry in table VII-2.

It is anticipated that increases in industrial water needs after the year 2020 will be offset to some extent by improved efficiencies in water use and more extensive use of air cooling. As discussed in Chapter VI, growth in the petroleum industry (the principal water-using industry in the study area) will probably level off within the next 50 to 60 years. For the reasons mentioned above, water requirements for this industry beyond the year 2020 are expected to decline.

Table VII-1

Study Area Municipal Water Use and Water Supply Data

County Area Designation	Population Served (1,000's)	Present Average Demand (mgd)	Source	Estimated Firm Yield or Dependable Draft (mgd)
Osage				
Pawhuska	6	.5	Bird & Clear Creeks Blue & Paw Lakes	1.3
Hominy	4	.3	Old & Upper Lakes & Hominy Municipal Lake	0.7 a/
Pawnee				
Cleveland	3	0.2	Cleveland Lake	0.5 a/
Tulsa				
Collinsville	3	.1	Caney River & Oologah Res.	1.3 a/
Tulsa	295	42.5	Upper & Lower Spavinaw Lakes	100.0
			Oologah Reservoir b/	39.0
Sand Springs	12	1.8	Shell Creek Reservoir	2.0
Broken Arrow	8	0.7	10 Wells	1.5
Creek				
Sapulpa	15	2.0	Rock & Ocher Creeks & Several Reservoirs	2.0
Drumright	4	0.5	10 Wells	1.5
Bristow	5	0.3	19 Wells	0.8
Okmulgee				
Okmulgee	20	3.0	Salt Creek & Lake Okmulgee	7.0
Henryetta	10	1.6	Henryetta Lake & Wolfe Creek	3.0
Muskogee				
Muskogee	40	6.0	Ft. Gibson Reservoir	50.0
Wagoner				
Wagoner	6	0.7	Ft. Gibson Reservoir	-- c/
	431	60.2		210.6

a/ Estimate.
b/ The city of Tulsa has firm commitments for storage to yield 39 mgd.
c/ See above.

Source: State-Federal Municipal Water Facilities Inventory 9/, and City Water Departments and City Engineers

Table VII-2

Projected 2020 Industrial Water Requirements
in the Study Area

Industry	2020 Production	Unit Water Use	Water Requirements (mgd)		
			Misc. (Sanitary & Process)	Cooling Water	Total
Thermal Power Generation	62.7 KWH/Cap/Day*	0.7 Gal/KWH		70	70
Petroleum Refining	375,000 Bbl/Day	309 Gal/Bbl**	19	97	116
Petrochemical Production	3,320 Tons/Day	14,458 Gal/Ton**	8	40	48
Food & Kindred Production	--	--	3		3
			30	207	237

*Kilowatt-hours per capita per day.
**Includes water used for all purposes.

Since industrial production was not projected beyond the year 2020 in this study, 2070 industrial water requirements are estimated based on an anticipated per capita industrial water use. Per capita industrial water use in the year 2020 (as determined from projected population and industrial water requirements) will be approximately 150 gpd. Based on expected changes in industrial water use, as mentioned above, a per capita industrial water use of 120 gpd is projected for this area by the year 2070. Application of this rate to the projected 2070 population indicates a 2070 industrial water need of 436 mgd.

Rural Water Use

A small portion of the total water need in the study area is that of nonmunicipal water supply for purposes other than irrigation. Generally, this includes domestic water for that portion of the population not served by municipal water systems and water for the maintenance of livestock. The projected 2070 requirements for rural water are estimated to be 11 mgd, based on a nonmunicipal per capita use of 140 gpd.

Irrigation

Irrigation in the study area occurs largely along the Arkansas River in Osage, Tulsa, and Muskogee Counties. Most of the irrigation water is obtained from wells in the alluvial aquifer. In view of increasing urbanization throughout this area, no additional increase in irrigation water use is projected.

VIII. WATER QUALITY CONTROL

A major factor in the development of the water resources of any sector of the country is the problem of waste disposal. Thorough water planning for an area must include not only adequate water supplies for municipal and industrial users, but must also insure that adequate assimilative flows exist in the streams which receive the treated waste of an area. Otherwise, as it has been found, municipal and industrial waste waters (even after a relatively high degree of treatment) may degrade the quality of a receiving stream to the point where fish and wildlife, recreation, water supply, and other uses of the stream will be impaired.

Congress emphasized the importance of water quality control as it applies to our Nation's water resources by the enactment of the Federal Water Pollution Control Act, Public Law 84-660, as amended by Public Law 87-88. Under the provisions of this act, consideration must be given to the inclusion of storage for regulation of streamflow to control water quality in any reservoir being planned by a Federal construction agency. Storage and release of this water are not to be provided as a substitute for adequate treatment of wastes at the source.

Municipal, Industrial, and Agricultural Pollution

In 1962, approximately 33 mgd of municipal waste flows with an estimated population equivalent of 135,000 were discharged into study area streams. The bulk of these discharges occurred in the vicinity of Tulsa. About half of the city's wastes (10.6 mgd) are given only primary treatment and released to the Arkansas River. The remainder (11.5 mgd) receives secondary treatment and is discharged into Bird Creek, a tributary of the Verdigris River. Muskogee and Okmulgee are the only other major sources of municipal waste discharge in the study area. The city of Muskogee currently discharges about 5 mgd of waste flows to the Arkansas River after primary treatment. Waste flows from Okmulgee average about 2 mgd and are released after secondary treatment to the Deep Fork of the Canadian River. Other substantial but minor sources of municipal waste discharge in the study area include the towns of Sapulpa, Sand Springs, Broken Arrow, and Henryetta. The first three communities provide secondary treatment and discharge their wastes (totaling 1.6 mgd) either directly or by tributary to the Arkansas River. The latter community releases its wastes after secondary treatment to Coal Creek, a minor tributary of the Deep Fork in the Canadian River system.

Industrial waste flows in the study area are principally those of the petroleum, petrochemical, and food processing industries. A preliminary study 10/ was made by the Public Health Service and further studies are under way to determine the sources, nature and extent of industrial pollution entering the main stem of the Arkansas River in the study area.

On the basis of anticipated industrial development and present and planned water use, it is expected that the bulk of future industrial water use in the study area and consequently industrial waste discharges will be cooling water as indicated in Chapter VII.

Present irrigation return flows to study area streams appear negligible. As indicated in Chapter VI, total estimated cropland under irrigation within the area in 1959 was less than 2,500 acres.

Water Quality Objectives

Evaluation of future stream conditions and the subsequent need for water quality control in the study area is based on parameters of water quality which are currently available for use. To meet the objectives of this study, two broad parameters, dissolved oxygen content and dissolved solids, are used. Dissolved oxygen consumption is used as a measure of the organic waste load (those constituents which will decompose in the stream). Dissolved oxygen is one of the most meaningful measures of water quality for which predictive techniques can be applied. It is also a vital factor in maintaining an environment for propagation of fish and other aquatic life. As a basis for the water quality objectives of this study, a minimum dissolved oxygen content of 4 mg/l in study area streams is considered necessary to prevent nuisance conditions from occurring and support fish life and maintain recreation and other uses of the streams.

Dissolved solids are employed to characterize the effects of stable pollutants (those constituents which are not utilized or reduced by the stream environment), such as chloride and sulfate salts. These constituents are generally not affected in the treatment of municipal wastes. Because of cathartic effects and taste and laxative properties, dissolved solids in excessive amounts are undesirable in waters used for public water supplies. By abatement of natural and manmade chloride pollution, much can be done toward improving the mineral quality or dissolved solids content of study area streams. As indicated in earlier sections of the report, efforts are being made to substantially reduce mineral pollution entering the study area. Full utilization of study area water resources may depend on the outcome of these activities. As a basis for the water quality objectives of this study, water quality control by streamflow regulation is considered desirable when the concentration of dissolved solids and other chemical constituents in finished drinking water supplies exceed the upper limits of the Public Health Service Drinking Water Standards-1962.

Waste Loadings

Based on projected waste return flows to the Arkansas River in the study area, water quality control needs for which storage in Keystone Reservoir can be provided will be centered largely at Tulsa. Provision of adequate streamflow in the reach of the river to assimilate future waste discharges of the greater Tulsa area (including Sand Springs, Sapulpa, and Broken Arrow) will assure water quality downstream from this point.

For planning purposes in this study, it is assumed the city of Tulsa will continue to discharge adequately treated municipal wastes into the Bird Creek - Verdigris River system until present and planned water pollution control capabilities of the Bird Creek water system are equalled. The portion of the city's wastes released to the stream is expected to continue at or near the present ratio (between 50 and 60 percent).

The remaining municipal waste flow and all major industrial flows (in view of present industry locations) are expected to be released after adequate treatment to the Arkansas River. Further, all additional waste releases resulting from growth of the city, changes in per capita water use, etc., after the Bird Creek system reaches its design capacity are also expected to be routed to the Arkansas River.

In evaluating the need for storage for water quality control purposes in the study area, expected amounts of future municipal and industrial waste return flows were estimated and the following criteria or conditions assumed:

1. Sufficient treatment will be provided to remove 90 percent of the BOD from treated municipal and industrial waste waters. The assumed level of BOD removal is based on the following considerations:

   a. As an outgrowth of extensive pollution abatement activities now underway and under consideration in the study area, high effluent standards can be expected of future waste treatment facilities in the area.

   b. The conveyance of sanitary sewage and storm drainage by separate collecting systems is now a common practice in the study area. Storm drainage and infiltration are not expected to significantly affect future treatment of municipal and industrial waste flows in the area.

   c. Modern waste treatment plants in the southwest are frequently reporting rates of BOD removal greater than 90 percent.

2. No dissolved solids removal will be achieved by treatment.

Flow Regulation

In determining the amount of water from storage required to preserve the quality of the stream, it is necessary to make allowances for natural flows that can be expected to occur in the stream in absence of the project. U.S. Geological Survey streamflow records of

the Arkansas River at Tulsa are shown in Appendix B, table B-1, for the period April 1926 through March 1963. These unregulated flows provide a measure of the river's natural waste assimilative capacity and form a basis (as described in Appendix B) on which can be established the need for flow regulation or supplemental water quality control releases.

Annual Draft-on-Storage Needed to Control Water Quality

An analysis of the procedure used in evaluating storage requirements for water quality control purposes is shown in Appendix B.

A summary of the storage requirements for control of water quality below Keystone Reservoir is given in table VIII-1.

Table VIII-1

Annual Draft-on-Storage Needed for Water Quality Control Below Keystone Reservoir*
(acre-feet)

Year	Percent of Time Water Quality is Protected		
	95	90	80
1980	-	-	-
2000	3,200	--	-
2020	55,000	25,000	1,700
2070	220,000	150,000	75,000

*Releases required in excess of natural streamflow. (See Appendix B.) The management of flow releases for quality control should be based on a system of water quality monitoring and streamflow forecasting to assure the most effective use of storage provided.

For purposes of this study, it is concluded that the draft-on-storage at the 95 percent protection level will be needed to assure adequate protection of water quality in the receiving stream and attain full utilization of the water resources of that portion of the Arkansas River within the study area.

Values of water quality control storage are, therefore, based on annual draft-on-storage of zero acre-feet by the year 1980, 3,200 acre-feet by the year 2000, 55,000 acre-feet by the year 2020, and 220,000 acre-feet by the year 2070. However, the draft-on-storage could not be provided from Keystone Reservoir to the year 2070 without reallocation of reservoir storage space.

IX. WATER SUPPLY AND WATER QUALITY CONTROL PLAN

Water Supply

Present and planned water supplies of study area communities appear adequate to meet most of the projected municipal and industrial water needs of these areas.

Plans for meeting the future water needs of Bristow, Okmulgee, and Henryetta are presented in the Public Health Service report of the Deep Fork River basin. 31/ The towns of Muskogee and Wagoner have adequate water supplies in the Grand (Neosho) River basin to meet foreseeable water needs. The community of Collinsville is now supplied by the Caney River and Oologah Reservoir, and is expected to continue to derive its water needs from these sources.

The city of Tulsa is now developing a water supply system aimed at meeting the long-range water needs of the Tulsa area. In addition to Spavinaw Lakes (existing), the city will utilize storage in Oologah Reservoir (initial phase completed), and possibly from Skiatook Reservoir (planned). The city also plans to divert water from the Grand River, Illinois River, and Spring Creek in the Illinois watershed. 32/ Based on existing and planned supplies, the water supply system of the greater Tulsa area a/ will be capable of providing over 430 mgd 32/ which is adequate to meet projected municipal and industrial water needs (excluding cooling water) of the area through the year 2040.

If upstream natural and manmade salt pollution is eventually controlled as is expected and adequate storage can be provided (some reallocation might be necessary), Keystone Reservoir will become a desirable source for satisfying additional municipal water needs of the Tulsa area. Without this source and to obtain water supply yields of the magnitude needed, the city will have to seek additional water supplies at considerable distance from the city. Most of the available storage in nearby projects not now contracted for by Tulsa is committed to other uses. As part of the city's present plans for meeting future needs, water will be piped from over 60 miles away.

It is anticipated that the Tulsa area will have need for an additional 152 mgd of water to meet municipal uses by the year 2070. Initial operation of Keystone Reservoir will provide 20,000 acre-feet

a/ Including Sand Springs, Broken Arrow, and Sapulpa.

of water supply storage. However, depending on the coordinated system of operations employed with development of future upstream projects,* the need for sediment and flood control storage in the Keystone project may be reduced thereby allowing reassignment of storage to water supply purposes should the need develop. The existing 20,000 acre-feet of water supply storage might also be used to re-regulate water supply releases from upstream storage.

Heavy water-using industries in the Tulsa area are now located along the Arkansas River and in some instances are now using the river as a source of industrial cooling water. Since construction of Keystone Reservoir, water of a more uniform mineral quality and more dependable flow could be made available to meet the cooling water needs of industry in this area. Several industries have already indicated an interest in obtaining water from the project. As industrial water needs increase, it is expected that storage in Keystone Reservoir (if it can be made available) will provide the principal source of industrial cooling water supply in the area.

Projected storage needs (in addition to other sources**) for industrial cooling water in the Tulsa area are expected to be 84 mgd by the year 2020, and 159 mgd by the year 2070.

The community of Pawhuska is now supplied by Bird and Clear Creeks, and two small impoundments with a total system yield estimated at 1.3 mgd (table VII-1). It is anticipated the town will need to increase its present supply within the next few years and in view of the distance and attendant costs of transmission from Keystone Reservoir will seek sources within the Bird Creek or Caney River watersheds.

Projected water needs for the remaining study area communities are small and it is anticipated could be served by further expansion of existing supplies or from rural water districts.

The amount of water, if any, such districts might desire from the Keystone Reservoir cannot be foreseen at this time.

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*A number of new projects are under consideration in the Arkansas River basin above Keystone Reservoir. The Kaw Reservoir project (approximately 100 miles upstream - see figure III-1) was recently authorized for construction.

**It is anticipated that some use will also be made of treated municipal waste discharges in satisfying long-range cooling water needs of this area, and that a substantial amount of cooling water will continue to be taken directly from the Arkansas River as has been done in past years.

Water Quality Control

A schedule of minimum flows needed to maintain water quality below Keystone Reservoir is shown in table B-2 of Appendix B.

Minimum monthly flows that would be maintained under the power operation plan adopted for Keystone Reservoir are shown in table III-2. As discussed in Chapter III, due to sediment deposits, regulation effects of the reservoir during drought periods are expected to decline by the year 2015 and become negligible by the year 2040. Assuming a fairly uniform rate of decline, regulated power releases from the reservoir appear sufficient to assimilate projected adequately treated waste discharges from the Tulsa area until the year 2020. After this time additional storage for regulation of streamflow or other measures for control of waste discharges will be needed if water quality is to be protected in the river below Tulsa.

X. BENEFITS

Municipal and Industrial Water Supply Benefits

General

Because of poor mineral quality, water entering the study area reach of the Arkansas River has remained largely unused for municipal and industrial water supply purposes. By leveling out peak salt loads, Keystone Reservoir will assure a more uniform mineral quality and will improve the attractiveness of the Arkansas River as a source of industrial water supply, particularly cooling water. While some use is now made of the river for cooling purposes, several industries in the area have indicated an interest in obtaining water from the project.

Assuming storage could be made available if needed (as discussed in Chapter IX), the reservoir would be an important source for supplying the projected long-range cooling water needs of the study area mentioned in Chapter IX.

With abatement of upstream salt pollution, the reservoir would also be the most likely source for supplying any additional long-range municipal and high quality industrial water needs of the area.

Senate Document No. 97 (87th Congress, 2nd sess.) states that when measuring benefits of storage in Federal reservoirs for municipal and industrial water supply purposes ". . .the measure of the benefit will be approximated by the cost of achieving the same results by the most likely alternative means that would be utilized in absence of the project." In the absence of the present Keystone project, it is expected that the city of Tulsa would have eventually constructed a single-purpose reservoir at or near the existing site to provide for all foreseeable low quality industrial cooling water needs with provisions for expansion at such time the waters are made usable for high quality municipal and industrial water supply purposes.

The cost of a single-purpose project constructed on the main stem of the Arkansas River near Tulsa and in the vicinity of the present project is therefore used as a measure of benefits to providing storage for municipal and industrial water supply purposes in Keystone Reservoir.

Costs and Water Supply Benefits

If adequate control of upstream natural and manmade salt pollution can be accomplished and storage can be made available when needed, the reservoir would have benefits to industrial (near future) and municipal (long range) water supply storage evaluated as follows.

The first cost and the annual operation, maintenance, and replacement costs for this reservoir are based largely on cost-yield curves developed by the Public Health Service using cost data of present projects in the region. Unit costs per 1,000 gallons of storage which were provided by the Corps of Engineers for the Keystone Reservoir in conjunction with the "Arkansas-Red River Basins, Water Quality Conservation," Benefits Evaluation study 28/ were also used as a guide.

On this basis, the cost of a project to yield 159 mgd (initially) for industrial water supply purposes would be $15,964,000 with an annual cost, including operation, maintenance, and major replacements, of $603,000 over a 100-year project life. Modifications to increase the yield of the project to 311 mgd (an additional 152 mgd) under the ultimate plan are estimated at $14,889,000. This would amount to an increased annual cost of $562,000, including operation, maintenance, and major replacements, over a 100-year project life.

Since initial project facilities would not be needed before the year 1995 an additional storage before the year 2040, recognition is given to the project salvage value at the end of the 100-year (1970-2070) study period. Based on the advantage of a longer period of service obtainable from a deferred investment as shown by Grant and Ireson, 29/ the total annual value of water supply storage in the project over the full 100-year period of study would be $415,000 ($359,000 for initial construction and $56,000 for additional facilities to be added by 2020).

Water Quality Control Storage Benefits

Benefits attributable to storage for streamflow regulation for water quality control may be tangible, i.e., have a measurable dollar value, or intangible, with no measurable dollar value. Such benefits are defined as the net contribution to public health, safety, economy, and effectiveness in use and enjoyment of water for all purposes which are subject to detriment or betterment by virtue of change in water quality.

Representing intangible benefits, water quality control management by Keystone Reservoir will provide recreational opportunities in the Arkansas River for a distance of approximately 80 miles from the Keystone Dam to the confluence of the Arkansas and Grand (Neosho) Rivers near Muskogee, Oklahoma. As indicated in Chapter VI, the urban population of the study area is projected to be on the order of 3.5 million by the year 2070. All would be within an easy drive of the river and able to enjoy the opportunities it would offer. In

*The sequence of building would necessarily begin about 10 years before the time of first need (the indicated year) and would allow for planning and construction and would protect against annual fluctuations of water demand.

addition to the recreational benefits, riparian property owners will enjoy improved aesthetics of the stream stemming from clean surface waters and a satisfactory public health water environment.

Supplemental flow regulation releases recommended for water quality control below Keystone Reservoir will protect sport fishing (estimated currently in the neighborhood of 5,000 man-days per year) in this reach of the river. It is further anticipated that by maintaining a minimum streamflow of 300 cfs (this could be met by projected water quality control releases), sport fishing in this reach of the river would be improved by 10,000 man-days per year.* By providing these releases during the summer months when water quality control needs are the most severe, sufficient flow will be maintained in the stream to permit higher species of game fish to live in the area.

Construction of Keystone Reservoir will provide water of a more uniform mineral quality for industrial water users in the study area. It was pointed out in Chapter VII that principal industrial water users in the study area in future years are expected to be for cooling purposes. As indicated from findings in previous studies 6/ in which surveys were made of power companies, manufacturing companies practicing cooling water recirculation, and consulting laboratories specializing in industrial water problems, if a dependable range in dissolved solids can be assumed prior to the construction of initial cooling water facilities, the facilities can be planned so that waters of up to 2,000 mg/l dissolved solids can be used as industrial cooling water with no appreciable increase in cost.

By capturing flood flows and diluting the normally high mineral concentrations in the river, Keystone Reservoir will maintain dissolved solids concentrations below this level a majority of the time. While benefits to improvement in mineral quality are not readily discernable, it is expected that the stabilizing effects of the project will encourage greater use of Arkansas River water, both from storage and from the river downstream.

As indicated earlier, because of the prospects of a more predictable water quality and an assured yield, several industries have already indicated an interest in obtaining water from the project.

If required storage for streamflow regulation is not provided as recommended, benefits described above will not be realized. Without streamflow regulation, it is estimated that the projected waste loads of 56 tons of BOD per day will result in a dissolved oxygen concentration in the river at times approaching zero. This means that most of the fish life in the stream will leave the area in favor

*Findings of the Fish and Wildlife Service.

of waters that more nearly provide the environment they require. If the dissolved oxygen concentration drops near zero, the stream could become the source of noxious odors and paint-blackening fumes. Recreation would suffer and property values would be expected to decline in areas contiguous to the stream.

Senate Document No. 97 permits the following method of measuring benefits of storage in Federal reservoirs for water quality control:

> "In situations where no adequate means can be devised to evaluate directly the economic effects of water quality improvement, the cost of achieving the same results by the most likely alternative may be used as an approximation of value."

This alternative cost method was used to determine the value of storage in Keystone Reservoir for water quality control purposes.

Several alternative plans could possibly be developed to maintain satisfactory quality in the Arkansas River in lieu of flow regulation by Keystone Reservoir. Those considered most feasible or applicable to the situation at hand include: (1) Constructing a single-purpose reservoir to regulate streamflow for control of water quality. (2) Piping treated municipal and industrial waste flows from the Tulsa area to a point downstream where streamflow would be adequate to assimilate the treated waste discharges. (3) Provide advanced waste treatment (tertiary treatment) for the city's future secondary treated discharges so that waste assimilative capacities of the Arkansas River below Tulsa will not be exceeded.

Of the three alternatives investigated, the first appears the least costly. It would require construction of a project to yield 197 mgd (annual draft-on-storage of 220,000 acre-feet). Since the Arkansas River provides the best reservoir site for a project to yield this amount the cost of a single-purpose project near the present site is used.

The first cost and the annual operation, maintenance, and replacement costs are based on the reservoir cost data mentioned earlier in the analysis of municipal and industrial water supply benefits. The estimated reservoir cost is $19,424,000. Using an amortization period of 100 years and a Federal interest rate of 3 1/8 percent, the equivalent annual cost and value of water quality control storage in Keystone Reservoir would be $733,000.

Since storage would not be needed before the year 2000, the project would have a useful life beyong the 100-year period of study. Computed as before, the total annual value of water quality control storage over the 100-year study period would be $367,000.

For purposes of comparison, the estimated annual value (over the 100-year study period) of piping treated waste flows to a point downstream is $1,158,000. This value is based on collecting treated waste discharges which exceed the waste assimilative capacity of the river at Tulsa (largely between June and October) and routing them to a point below confluence with the Arkansas and Neosho Rivers (about 45 miles downstream). The estimated annual value of providing advanced waste treatment for the above waste discharges is $1,103,000. This is based on the cost of adsorption or use of granular activated carbon to reduce the BOD of secondary treated waste flows to low levels which would not significantly effect stream quality.

Calculations used in computing value of storage for municipal, industrial, and water quality control purposes are shown in Appendix C.

Since water quality control management by the proposed Keystone Reservoir will assure maintenance of the dissolved oxygen quality of the Arkansas River for a distance of approximately 80 stream miles and thereby provide recreational opportunities for an estimated potential population of over 3.5 million, and enhance use of the stream by future industry located within the study area, benefits to water quality control storage in the project are considered widespread in scope.

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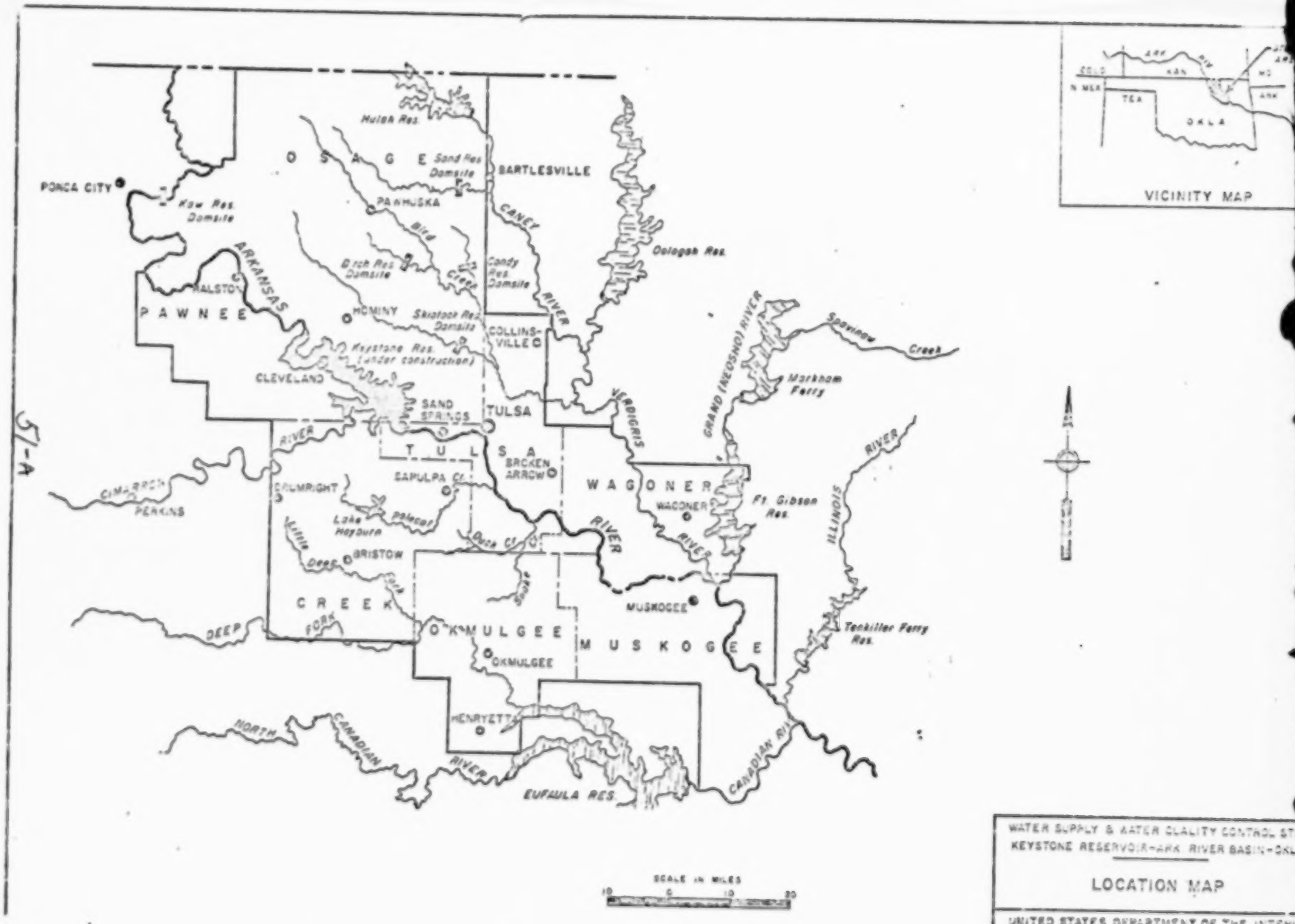


WATER SUPPLY & WATER QUALITY CONTROL ST...
KEYSTONE RESERVOIR-ARK. RIVER BASIN-OKL...

LOCATION MAP

UNITED STATES DEPARTMENT OF THE INTERIO...
Federal Water Pollution Control Administration
Date ... Jan. 15, 1968 ... DALLAS, TEXAS

FIGURE III-...

5/-A

APPENDIX A

Analysis of Mineral Quality - Keystone Reservoir

Poor mineral quality in the study area reach of the Arkansas River presently limits use of the main stem as a potable or industrial water source. For the 15-year period ending in 1962, the concentration of dissolved solids in the river at Tulsa ranged from 521 to 5,650 mg/l with a median concentration of 2,130 mg/l. As indicated by the correlation in figure A-1, about 51 percent of these minerals are chlorides. The comparative concentration of sulfates for this period was 191 mg/l. In a typical year, total hardness will vary from 200 to 800 mg/l with noncarbonate hardness of 100 to 400 mg/l.

Although other mineral constituents contribute to the poor quality of water, as indicated above, the chloride ion has generally been the limiting factor in municipal and industrial water use.

The effect of Keystone Reservoir and existing and authorized projects upstream (principally Kaw Reservoir) in smoothing out chloride concentrations in the river is shown by figure A-2.

As shown by this curve, chloride concentrations in Keystone Reservoir, though substantially lower and of a more predictable nature, will still exceed the upper limit (250 mg/l) of the Public Health Service Drinking Water Standards more than 95 percent of the time.

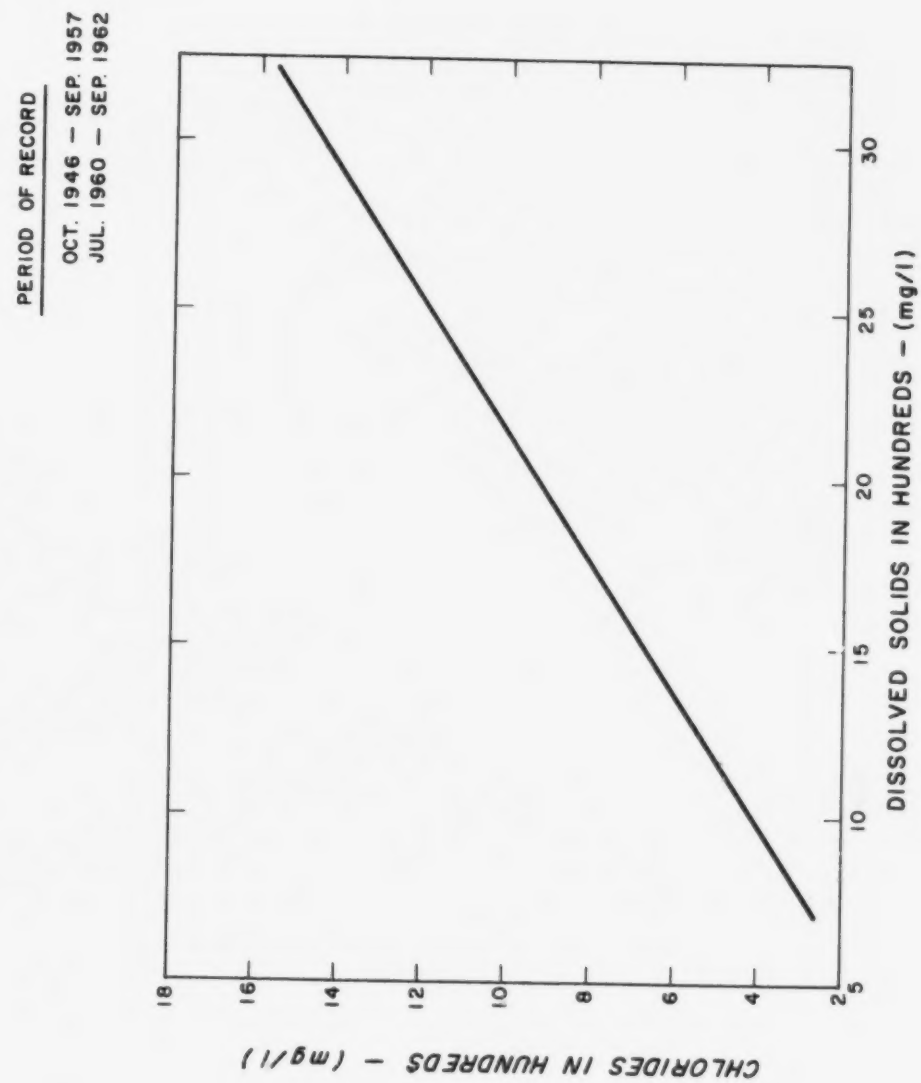
The importance of the reservoir in leveling out mineral loads will be significantly enhanced if the pollution abatement objectives of the Arkansas-Red River Basins Water Quality Conservation Project are achieved. 6/ The project proposed control of both natural and manmade chloride pollution in the two basins where feasible. At the present time, an estimated 9,500 tons of chloride (Cl^-) pass the city of Tulsa daily. These loads are attributed to natural and manmade upstream salt pollution. Manmade salt pollution is largely attributed to oil and gas, and salt recovery industries.

Figure A-2 shows the expected chloride concentrations in Keystone Reservoir as modified by existing and authorized projects and maximum anticipated control of natural and manmade chlorides as proposed in the above water quality study.

If these controls are imposed, it can be seen from curve C, that chloride concentrations in the reservoir will be within the upper limit of the Public Health Service Drinking Water Standards 100 percent of the time and less than 100 mg/l about 50 percent of the time.

Further, since chlorides make up a major part of total dissolved solids, as shown previously, a reduction of chloride concentrations to these levels will greatly improve dissolved solids concentrations in the reservoir. This is illustrated in figure A-3. The dissolved solids duration curves shown on figure A-3 are based on a correlation of dissolved solids with stream discharge at Tulsa for the 15-year period ending in 1962 (figure A-4) and a reservoir inflow and operation schedule provided by the Corps of Engineers for the streamflow period October 1937 to September 1962.

Curve A on figure A-3 illustrates the expected dissolved solids duration curve for Keystone Reservoir with existing mineral loadings while figure B represents dissolved solids concentrations expected to exist in the reservoir with maximum anticipated control of both natural and manmade chlorides now entering the reservoir. The leveling out effects of reservoir storage on dissolved solids concentrations is shown to some extent by comparing curve A on figure A-3 with the concentration duration curve of the Arkansas River near Tulsa under natural flow conditions on figure A-5. While the two curves are not directly comparable (one measures the likely occurrence of an annual average concentration and the other a monthly average concentration) close investigation of the two curves indicates substantial quality improvement will occur with reservoir storage. Figure A-5 indicates that under natural stream flow conditions an average monthly dissolved solids concentration of about 2,000 mg/l or better could be expected about 50 percent of the time (six months of the year). Figure A-3 indicates that with reservoir storage and mixing the concentration of dissolved solids in the reservoir will be equal to or less than 1,500 mg/l about 50 percent of the time. At the extreme ends of the curves high reservoir concentrations (curve A on figure A-3) could be expected to be substantially lower than the peak monthly concentrations shown on figure A-5 with the reverse true for low concentrations.

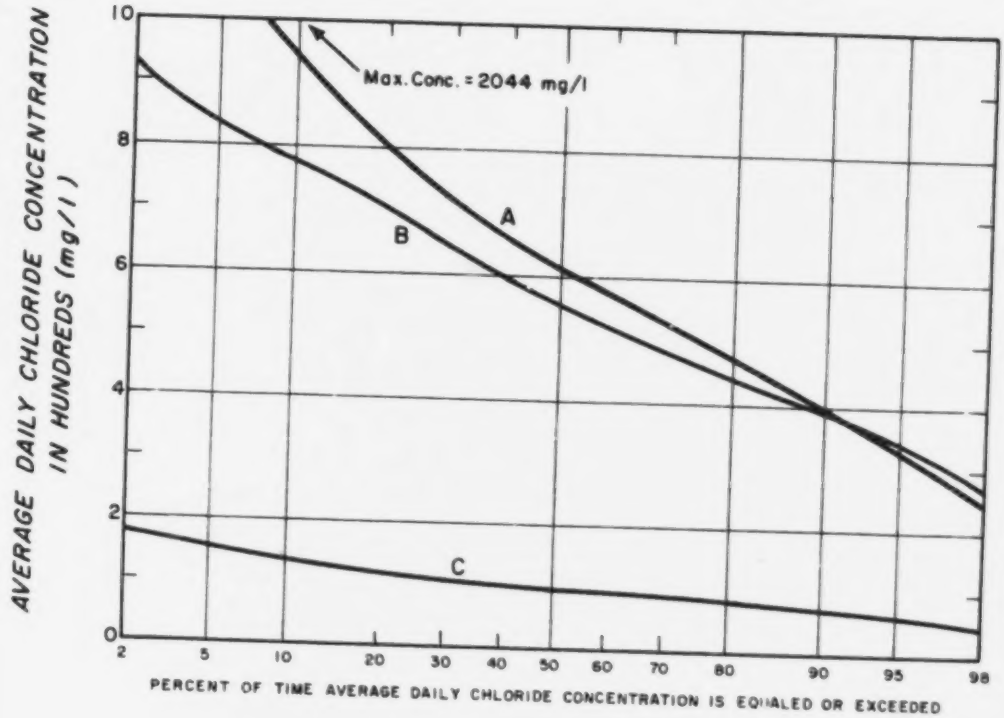


WATER SUPPLY & WATER QUALITY CONTROL STUDY
KEYSTONE RESERVOIR – ARK. RIVER BASIN – OKLA.

DISSOLVED SOLIDS – CHLORIDE RELATIONSHIP – ARKANSAS RIVER (TULSA)

UNITED STATES DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Date – – Jan 15, 1966 DALLAS, TEXAS

FIGURE A – 1



NOTE

A. CONCENTRATION DURATION CURVE WITH NATURAL FLOWS (PAST THE KEYSTONE DAM) AND CHLORIDES.

B. CONCENTRATION DURATION CURVE WITH EXISTING CHLORIDES AND FLOWS MODIFIED BY EXISTING AND AUTHORIZED RESERVOIRS.

C. CONCENTRATION DURATION CURVE WITH FLOWS MODIFIED BY EXISTING, AUTHORIZED, AND PROPOSED WATER QUALITY STUDY STRUCTURE WITH MAXIMUM ANTICIPATED CONTROL OF NATURAL AND MAN-MADE CHLORIDES.

SOURCE: U.S. ARMY ENGINEER DISTRICT, TULSA – SURVEY REPORT ON ARKANSAS – RED RIVER BASINS WATER QUALITY CONTROL STUDY (PART I) VOL. 4, APPX. VI.

WATER SUPPLY & WATER QUALITY CONTROL STUDY
KEYSTONE RESERVOIR – ARK. RIVER BASIN – OKLA.

KEYSTONE RESERVOIR CHLORIDE CONCENTRATION DURATION CURVES

UNITED STATES DEPARTMENT OF THE INTERIOR
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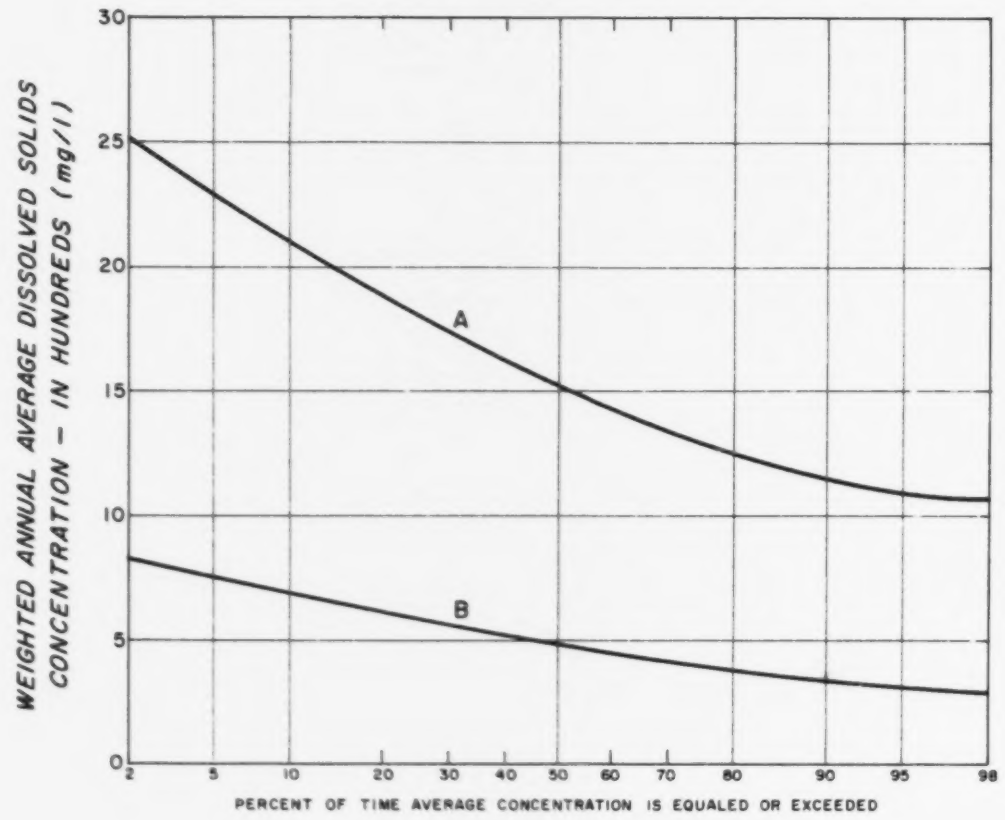
Date -- Jan. 15, 1966 DALLAS, TEXAS

FIGURE A-2



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NOTE

A. WITH EXISTING MINERAL LOADINGS

B. WITH MAXIMUM ANTICIPATED CONTROL OF NATURAL AND MANMADE SALT POLLUTION

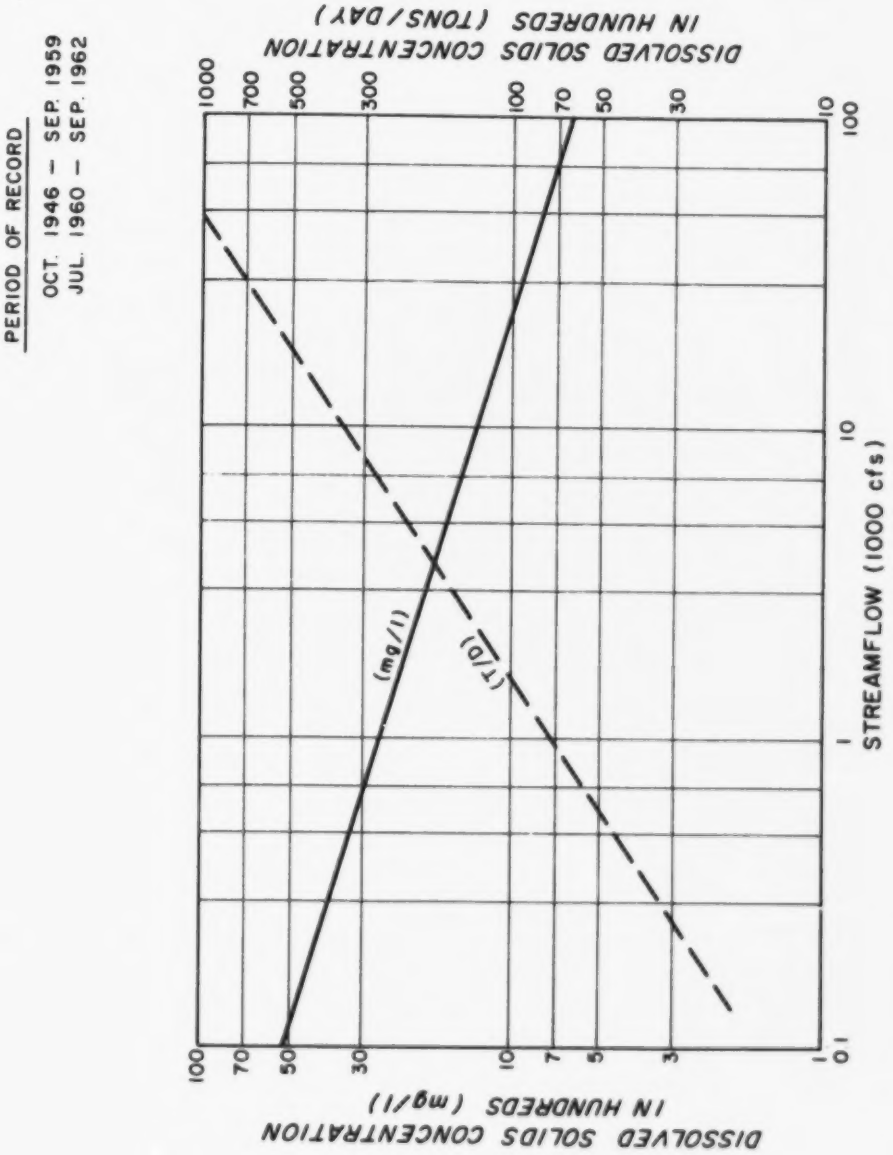
PERIOD OF FLOW RECORD - 1937 - 1962
STORAGE UTILIZED - 663,000 ACRE-FT.
WATER QUALITY RECORDS USED - TULSA
OCT. 1946 - SEP. 1959
JUL. 1960 - SEP. 1962

WATER SUPPLY & WATER QUALITY CONTROL STUDY
KEYSTONE RESERVOIR - ARK. RIVER BASIN-OKLA.

KEYSTONE RESERVOIR DISSOLVED SOLIDS CONCENTRATION DURATION CURVES

UNITED STATES DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Date -- Jan. 15, 1965 DALLAS, TEXAS

FIGURE A-3

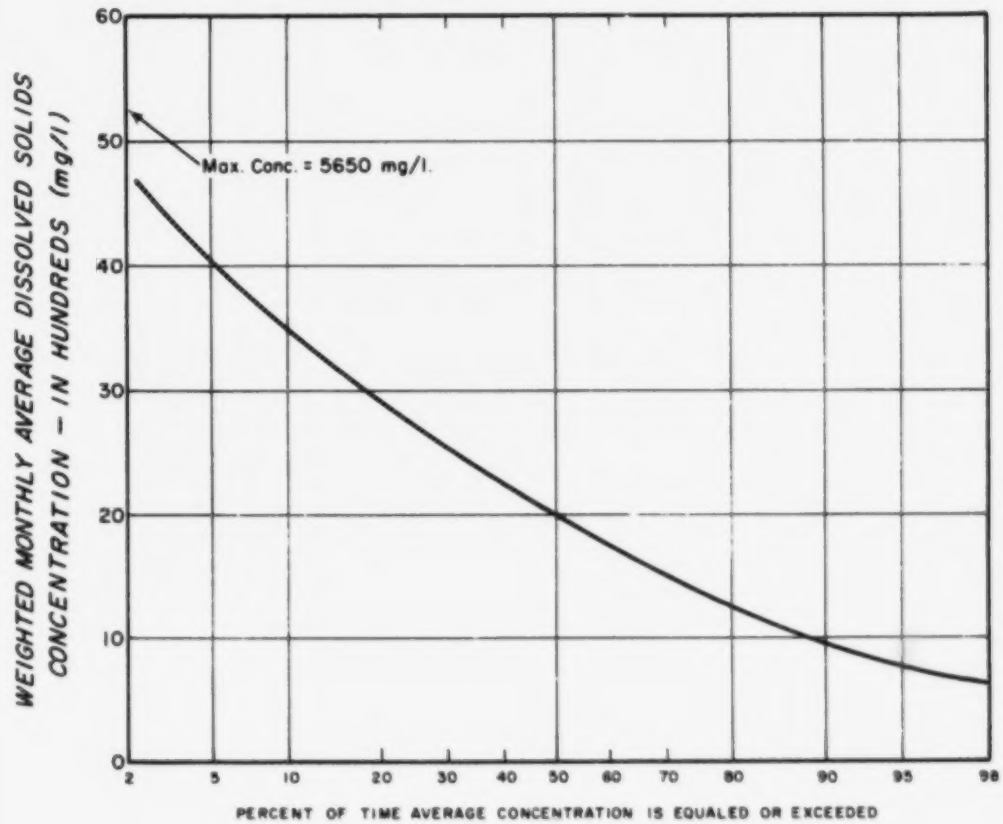


WATER SUPPLY & WATER QUALITY CONTROL STUDY
KEYSTONE RESERVOIR – ARK. RIVER BASIN–OKLA.

DISSOLVED SOLIDS–STREAM DISCHARGE RELATIONSHIP – ARKANSAS RIVER (TULSA)

UNITED STATES DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Date – – Jan. 15, 1966 DALLAS, TEXAS

FIGURE A–4



NOTE:

WATER QUALITY RECORDS USED - TULSA
OCT. 1946 - SEP. 1959
JUL. 1960 - SEP. 1962

WATER SUPPLY & WATER QUALITY CONTROL STUDY
KEYSTONE RESERVOIR - ARK. RIVER BASIN-OKLA.

DISSOLVED SOLIDS CONCENTRATION
DURATION CURVE
ARKANSAS RIVER-TULSA

UNITED STATES DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Date -- Jan. 15, 1966 DALLAS, TEXAS

FIGURE A-5

APPENDIX B

Water Quality Control Needs - Method of Analysis

In evaluating the need for streamflow regulation for water quality control below Keystone Reservoir, estimates of natural streamflow must be made for points where water quality problems are expected to occur.

Based on projected waste return flows to the Arkansas River in the study area, significant water quality control needs for which storage in Keystone Reservoir can be provided will be centered almost entirely at Tulsa. As discussed in the Public Health Service study, "Arkansas River Preliminary Studies, Tulsa Metropolitan Area," September 1964, consideration is being given to the construction of two small recreational reservoirs (low head dams) immediately below the Keystone re-regulation dam on the Arkansas River at Tulsa. (See figure III-2.)

To prevent pollution of these reservoirs, it is expected that wastes tributary to the receiving stream below Keystone Reservoir will be collected, treated, and discharged below the proposed recreational pools.

For purposes of this study, it is assumed that future waste discharges to the Arkansas River from Tulsa and vicinity will occur below the proposed damsite for the lower recreational pool. Provision of adequate streamflow in this reach of the river to assimilate future waste discharges of the greater Tulsa area (including Sand Springs, Sapulpa and Broken Arrow) will assure satisfactory water quality downstream from this point.

U.S. Geological Survey streamflow records of the Arkansas River at Tulsa, from April 1926 through March 1964, were used to evaluate flow regulation needs in the vicinity of the city. These data are shown in table B-1.

Minimum monthly flows which will be needed in the Arkansas River below Keystone Reservoir for water quality control are shown in table B-2. These flows represent minimum dilution needs (during periods of no streamflow) for assimilation of waste discharges to the Arkansas River below Keystone Reservoir.

Hydrographs of projected minimum monthly streamflow requirements shown in table B-2 (A), when compared to hydrographs of natural flows shown in table B-1, reveal monthly deficits as indicated by table B-3. These deficits are the supplemental water quality control requirements (Annual draft-on-storage) which will be needed to assimilate future waste discharges by the year indicated, based on streamflows as occurred during the corresponding climatic year.

Table B-1

Monthly Mean Discharge - Arkansas River At Tulsa, Oklahoma
(Cubic Feet/Sec.)

Climatic Year[a]	April	May	June	July	August	September	October	November	December	January	February	March
1926	4,280	2,280	7,510	2,980	2,070	8,830	24,800	2,910	3,070	2,270	2,780	4,840
1927	37,300	9,560	12,800	3,750	31,300	6,980	10,600	3,190	2,120	2,370	2,420	3,950
1928	9,040	8,860	27,200	10,000	4,470	1,610	1,110	12,500	7,120	8,340	3,940	7,080
1929	21,600	27,000	23,800	16,000	2,880	1,690	1,310	2,650	1,770	1,320	3,920	1,700
1930	1,220	19,000	9,100	1,860	1,210	2,320	1,760	2,140	2,140	1,270	1,210	1,320
1931	4,900	5,320	8,300	1,360	1,190	607	621	7,070	3,030	4,390	2,760	1,850
1932	1,280	1,700	7,770	8,510	6,670	1,090	1,050	568	1,710	907	706	2,110
1933	2,490	3,070	881	546	6,020	7,440	1,720	1,000	1,170	1,340	739	800
1934	4,090	3,010	1,020	305	545	4,440	2,750	3,370	1,360	955	832	2,250
1935	2,250	25,100	28,200	6,490	1,710	3,320	1,530	2,100	2,740	994	616	931
1936	331	1,270	8,360	620	424	2,040	5,370	1,040	797	1,520	2,370	1,820
1937	1,750	2,740	14,600	5,050	2,810	5,330	1,500	718	718	659	1,210	3,420
1938	3,183	24,840	15,390	4,417	6,788	3,220	945	2,097	917	1,023	1,022	1,073
1939	4,503	2,548	3,547	4,438	1,928	567	311	287	321	211	660	801
1940	2,390	4,942	4,233	3,245	1,715	7,966	713	2,607	2,019	2,077	3,141	1,959
1941	10,230	13,870	16,450	5,873	2,043	4,545	26,320	12,610	5,367	2,966	5,027	4,479
1942	36,320	17,250	28,260	9,472	8,033	11,450	9,511	4,272	5,521	5,883	4,128	2,854
1943	2,635	36,190	7,933	3,620	1,400	1,170	2,716	1,278	1,355	1,514	1,867	10,830
1944	40,540	21,250	12,000	5,563	3,877	5,024	10,470	3,939	15,520	3,795	3,493	11,000
1945	38,360	11,800	9,412	11,690	2,572	11,210	23,730	2,733	2,132	5,015	3,827	5,369
1946	3,606	4,106	2,539	2,344	613	1,201	2,061	3,687	2,205	1,723	1,417	5,195
1947	34,860	24,220	11,760	7,240	1,815	931	577	674	1,452	1,003	1,333	9,077
1948	3,789	3,395	12,860	34,110	18,070	3,647	1,689	4,562	3,513	12,630	29,690	12,770
1949	9,195	39,100	26,470	8,711	4,730	10,070	4,478	2,559	2,140	2,642	2,426	2,178
1950	1,690	6,145	5,643	18,930	32,880	10,280	4,631	2,430	2,243	2,241	3,654	3,443
1951	4,277	42,850	37,670	56,630	8,155	18,080	6,702	8,083	4,588	4,427	3,842	10,600
1952	9,215	7,646	6,635	1,476	1,404	691	378	631	940	1,106	1,194	2,525
1953	2,833	2,803	2,623	4,144	1,898	716	500	1,431	1,336	762	856	844
1954	906	5,115	2,811	416	196	156	271	240	243	392	523	650
1955	545	16,960	13,410	33,712	1,045	529	14,860	936	702	712	971	781
1956	761	720	897	908	261	89.5	125	245	210	214	311	407
1957	14,550	58,090	61,100	27,170	3,613	6,766	3,390	3,841	2,769	2,595	2,452	13,100
1958	11,970	6,498	9,149	19,900	9,791	7,206	3,082	1,920	1,747	1,743	2,155	2,182
1959	4,763	9,740	4,828	18,420	4,434	11,710	56,740	5,831	5,529	5,973	11,340	14,320
1960	11,420	13,100	13,570	10,980	11,810	6,892	6,493	6,166	4,010	2,305	3,498	4,884
1961	8,238	37,040	12,720	11,770	9,306	74,760	16,450	25,160	8,833	5,632	9,862	5,023
1962	4,256	2,640	16,310	8,908	5,565	7,232	4,344	2,462	3,132	2,195	2,780	3,783
1963	3,016	2,127	5,822	8,036	2,564	6,823	2,945	1,615	987	1,318	1,627	1,301

[a] April 1st - March 31st.

Source: Geological Survey [1-3]

Table B-2 (A)

Minimum Monthly Streamflow
Required For Water Quality Control[a/] & [b/]
Below Keystone Reservoir

	1980		2000		2020		2070	
	cfs	acre-ft	cfs	acre-ft	cfs	acre-ft	cfs	acre-ft
Jan.	14	844	25	1,508	69	4,161	165	9,950
Feb.	14	844	25	1,508	69	4,161	165	9,950
Mar.	14	844	25	1,508	69	4,161	165	9,950
Apr.	42	2,533	74	4,462	208	12,542	495	29,849
May	85	5,126	147	8,864	416	25,085	990	59,697
Jun.	120	7,236	208	12,542	590	35,577	1,403	84,601
Jul.	138	8,321	233	14,050	659	39,738	1,568	94,550
Aug.	172	10,372	294	17,728	832	50,170	1,980	119,394
Sep.	93	5,608	159	9,588	451	27,195	1,073	64,702
Oct.	50	3,015	86	5,186	243	14,653	578	34,853
Nov.	14	844	25	1,508	69	4,161	165	9,950
Dec.	14	844	25	1,508	69	4,161	165	9,950
TOTAL acre-ft		46,431		79,960		225,665		537,396
mgd		41.6		71.6		202.0		481.1

[a/] Minimum discharges (or releases) needed to maintain water quality in the Arkansas River at Tulsa. (This table is not to be taken as a recommended operating schedule but used only as an example of minimum anticipated streamflow needs.)

[b/] Based on providing adequate treatment (see chapter VIII) for all waste flows released to the stream in this area.

Table B-2 (B) shows projected minimum streamflows needed to protect water quality in the Arkansas River below Tulsa over the next 10-20 year period and based on the primary level of waste treatment now provided in waste discharges from the city to the Arkansas River. It is expected that actions will be taken to provide better treatment for waste flows to the river in this area within the coming years. Regulated power releases from Keystone Reservoir as shown in table III-2 would be beneficial in maintaining satisfactory water quality in the river until better treatment facilities can be provided.

Table B-2 (B)

Minimum Monthly Streamflow Required For
Water Quality Control Below Keystone Reservoir
(Present Conditions)[a/]

	1970		1980		1990	
	cfs	Acre-Ft	cfs	Acre-Ft	cfs	Acre-Ft
January	190	11,457	244	14,713	336	20,261
February	190	11,457	244	14,713	336	20,261
March	271	16,341	349	21,045	481	29,000
April	407	24,542	523	31,537	721	43,476
May	597	35,999	767	46,250	1,057	63,737
June	705	42,512	907	54,692	1,249	75,315
July	732	44,140	942	56,803	1,297	78,209
August	814	49,084	1,046	63,074	1,442	86,953
September	597	35,999	767	46,250	1,057	63,737
October	407	24,542	523	31,537	721	43,476
November	271	16,341	349	21,045	481	29,000
December	190	11,457	244	14,713	336	20,261

a/ These flows represent minimum expected streamflow needs below Keystone Reservoir to assimilate projected waste discharges from the Tulsa area through the year 1990 based on the current level of treatment provided in waste discharged to the Arkansas River in this area.

They are shown only to indicate the beneficial effects of regulated power releases (see table III-2) in maintaining stream quality until treatment facilities can be constructed to provide adequate treatment. Better facilities though not presently planned are needed. In view of plans by the city of Tulsa to use the Arkansas River for recreation 30/ and planned navigation development on the river (as near as Muskogee) it is expected that actions will soon be taken to provide better treatment for future waste discharges.

Table B-3

Supplemental Water Quality Control Requirements
Arkansas River Below Keystone Reservoir
1980, 2000, 2020, and 2070 [a/]

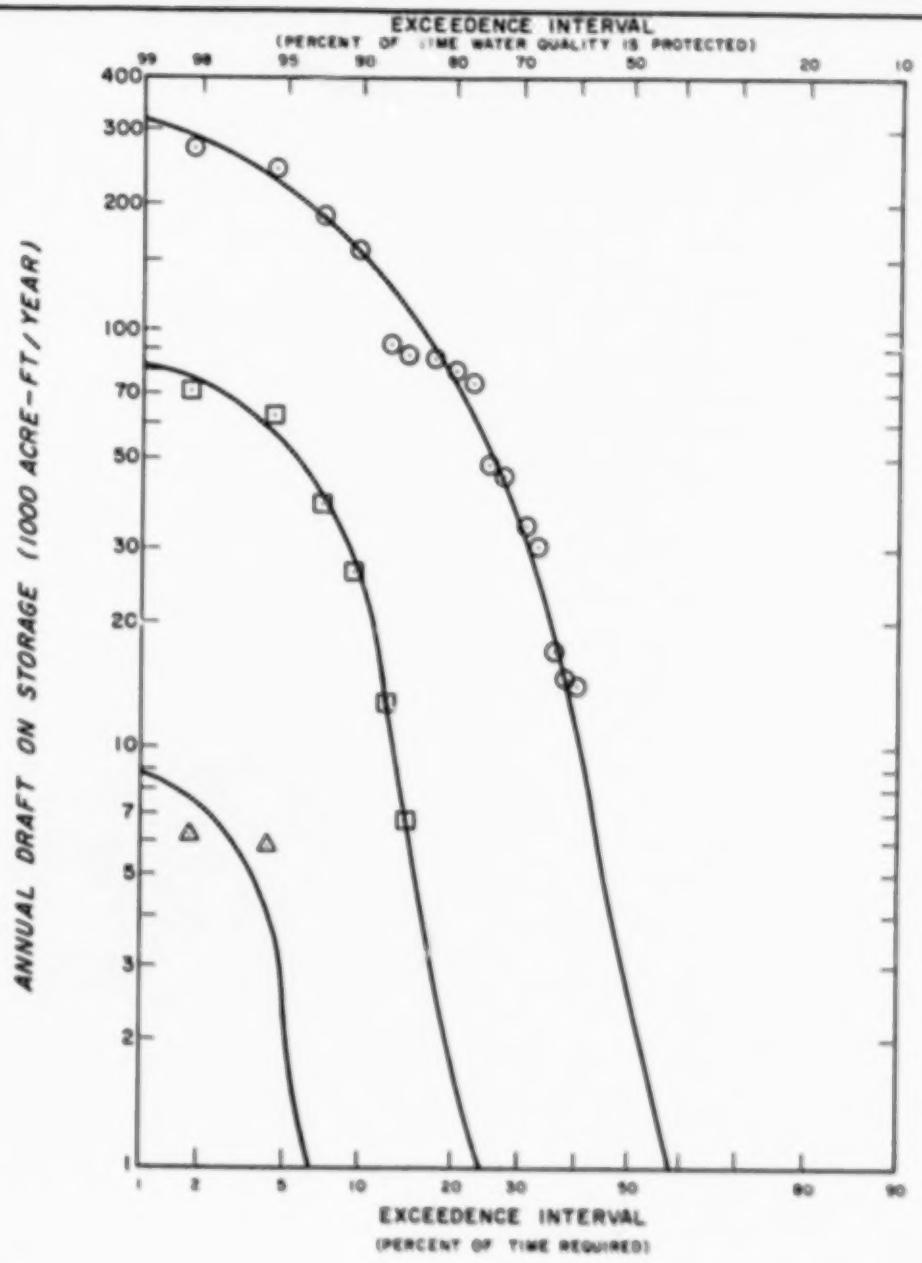
Climatic Year [b/]	1980		2000		2020		2070	
	cfs	acre-ft	cfs	acre-ft	cfs	acre-ft	cfs	acre-ft
1926	-	-	-	-	-	-	-	-
1927	-	-	-	-	-	-	-	-
1928	-	-	-	-	-	-	-	-
1929	-	-	-	-	-	-	-	-
1930	-	-	-	-	-	-	64.2	46,468
1931	-	-	-	-	-	-	121.9	88,231
1932	-	-	-	-	-	-	-	-
1933	-	-	-	-	9.4	6,804	128.6	93,081
1934	-	-	-	-	53.5	38,723	256.7	185,799
1935	-	-	-	-	-	-	22.5	16,286
1936	-	-	-	-	37.3	26,998	208.6	150,985
1937	-	-	-	-	-	-	-	-
1938	-	-	-	-	-	-	-	-
1939	-	-	-	-	-	-	68.7	49,725
1940	-	-	-	-	-	-	22.1	15,996
1941	-	-	-	-	-	-	-	-
1942	-	-	-	-	-	-	-	-
1943	-	-	-	-	-	-	48.3	34,960
1944	-	-	-	-	-	-	-	-
1945	-	-	-	-	-	-	-	-
1946	-	-	-	-	18.3	13,246	113.9	82,441
1947	-	-	-	-	-	-	25.5	18,457
1948	-	-	-	-	-	-	-	-
1949	-	-	-	-	-	-	-	-
1950	-	-	-	-	-	-	-	-
1951	-	-	-	-	-	-	-	-
1952	-	-	-	-	-	-	104.1	75,348
1953	-	-	-	-	-	-	43.0	31,123
1954	-	-	8.4	6,080	97.9	70,860	346.5	250,797
1955	-	-	-	-	-	-	123.2	89,172
1956	-	-	8.6	6,225	87.6	63,405	382.4	276,781
1957	-	-	-	-	-	-	-	-
1958	-	-	-	-	-	-	-	-
1959	-	-	-	-	-	-	-	-
1960	-	-	-	-	-	-	-	-
1961	-	-	-	-	-	-	-	-
1962	-	-	-	-	-	-	-	-
1963	-	-	-	-	-	-	-	-

[a/] Annual draft-on-storage needed for water quality control by the years indicated, and based on a comparison of monthly streamflow needs shown in table B-2 (A) with available monthly discharges shown in table B-1.

[b/] April through March.

Probability levels shown on figure B-1 are based on the supplemental streamflow needs shown in table B-3, and the plotting positions in table B-4. From figure B-1 can be determined the estimated draft-on-storage needed at various levels of water quality protection.

A summary of estimated storage requirements is given in table B-5.



LEGEND

△ YEAR 2000

□ YEAR 2020

○ YEAR 2070

WATER SUPPLY & WATER QUALITY CONTROL STUDY
KEYSTONE RESERVOIR — ARK. RIVER BASIN-OKLA.

ANNUAL DRAFT ON STORAGE FOR WATER QUALITY CONTROL BELOW KEYSTONE RESERVOIR

UNITED STATES DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
Date — Jan. 15, 1968 DALLAS, TEXAS

FIGURE B-1

Table B-4

Plotting Positions in Percent

	Storage Requirement (acre-feet)				M/N a/
	1980	2000	2020	2070	
1.	0	6,225	70,860	276,781	1.81
2.	0	6,080	63,405	250,797	4.4
3.	0	0	38,723	185,799	7.0
4.	0	0	26,998	150,985	9.6
5.	0	0	13,246	93,081	12.2
6.	0	0	6,804	89,172	14.8
7.	0	0	0	88,231	17.4
8.	0	0	0	82,441	20.0
9.	0	0	0	75,348	22.6
10.	0	0	0	49,725	25.3
11.	0	0	0	46,468	27.9
12.	0	0	0	34,960	30.5
13.	0	0	0	31,123	33.1
14.	0	0	0	18,457	35.7
15.	0	0	0	16,286	38.3
16.	0	0	0	15,996	40.9
17.	0	0	0	0	43.5
18.	0	0	0	0	46.1
19.	0	0	0	0	48.7
20.	0	0	0	0	51.3
21.	0	0	0	0	53.9
22.	0	0	0	0	56.5
23.	0	0	0	0	59.1
24.	0	0	0	0	61.7
25.	0	0	0	0	64.3
26.	0	0	0	0	66.9
27.	0	0	0	0	69.5
28.	0	0	0	0	72.1
29.	0	0	0	0	74.7
30.	0	0	0	0	77.4
31.	0	0	0	0	80.0
32.	0	0	0	0	82.6
33.	0	0	0	0	85.2
34.	0	0	0	0	87.8
35.	0	0	0	0	90.4
36.	0	0	0	0	93.0
37.	0	0	0	0	95.6
38.	0	0	0	0	98.2

a/ Median plotting position.

Table B-5

Annual Draft-On-Storage Needed
For
Water Quality Control
Below Keystone Reservoir

Year	Percent of Time Water Quality is Protected				
	95%	90%	80%	70%	40%
1980	-	-	-	-	-
2000	3,200	-	-	-	-
2020	55,000	25,000	1,700	-	-
2070	220,000	150,000	75,000	36,000	-

APPENDIX C

Benefit Calculations
Municipal and Industrial Water Supply

The cost of a single-purpose project near the existing site constructed to yield 159 mgd by the year 1995 and a total of 311 mgd by the year 2040 is considered a measure of benefits and the most likely alternative to providing storage for municipal and industrial water supply purposes in Keystone Reservoir. These costs are computed below:

Capital cost of alternative project to yield 159 mgd (initial construction)	$15,964,000 1/
Year of first need 2/	1995
Annual cost of alternative amortizing at a Federal interest rate of 3 1/8 % for the 100-year life of the project	
15,964,000 x 0.032759	523,000
Operation, maintenance & major replacements	80,000
Total Annual Cost	$ 603,000
Capitalized value of annual cost in year 1995 for 75-year period (1995-2070) 3/	
603,000 x 28.816881	$17,377,000
Capitalized value of annual cost in year 1970	
17,377,000 x 0.630290 4/	$10,953,000

1/ Based on 1965 ENR Construction Cost Index. Includes interest during construction.

2/ The sequence of building would necessarily begin about 10 years before the time of first need and would allow for planning and construction and would protect against annual fluctuations of water demand.

3/ Capitalized at 3 1/8% Federal interest rate for the length of time, 75 years (1995-2070), the project will be needed during the 100-year period of evaluation (1970-2070). Recognition is given here to the advantage of a longer period of service obtainable from a deferred investment as shown by Grant & Ireson. 29/

4/ Discounted from the time of construction (1985).

Annual value of alternative, amortizing at a Federal interest rate of 3 1/8 % for the 100-year study period (1970-2070)	
10,953,000 x 0.032759	359,000
Capital cost of alternative project expansion to yield a total of 311 mgd (ultimate plan)	$14,889,000 1/
Year of first need 2/	2040
Annual cost of alternative amortizing at a Federal interest rate of 3 1/8 % for the 100-year life of the project	
14,889,000 x 0.032759	488,000
Operation, maintenance & major replacements	74,000
Total Annual Cost	$ 562,000
Capitalized value of annual cost in the year 2040 for 30-year period (2040-2070) 3/	
562,000 x 19.287495	$10,840,000
Capitalized value of annual cost in year 1970	
10,840,000 x 0.157820 4/	1,711,000
Annual value of alternative (expansion), amortizing at a Federal interest rate of 3 1/8 % for the 100-year study period (1970-2070)	
1,711,000 x 0.032759	56,000

Water Quality Control Benefits

Alternate #1 - Constructing a single-purpose reservoir near the same site

1/ Based on 1965 ENR Construction Cost Index. Includes interest during construction.

2/ The sequence of building would necessarily begin about 10 years before the time of first need and would allow for planning and construction.

3/ Capitalized at 3 1/8% Federal interest rate for the length of time, 30 years (2040-2070), the project will be needed during the 100-year period of evaluation (1970-2070). Recognition is given here to the advantage of a longer period of service obtainable from a deferred investment as shown by Grant & Ireson. 29/

4/ Discounted from the time of construction (2030).

Capital cost of a project to yield 197 mgd	$19,424,000 1/
Year of first need 2/	2000 3/
Annual cost of alternate amortizing at a Federal interest rate of 3 1/8 % for the 100-year life of the project	
19,424,000 x 0.032759	636,000
Operation, maintenance & major replacements	97,000
Total Annual Cost	$ 733,000
Capitalized value of annual cost in year 2000 for 70-year period (2000-2070) 4/	
733,000 x 28.287446	$20,735,000
Capitalized value of annual cost in year 1970	
20,735,000 x 0.540407 5/	11,205,000
Annual value of alternative amortizing at a Federal interest rate of 3 1/8 % for the 100-year study period (1970-2070)	
11,205,000 x 0.032759	367,000

1/ Based on 1965 ENR Construction Cost Index. Includes interest during construction.

2/ The sequence of building would necessarily begin about 10 years before the time of first need and would allow for planning and construction.

3/ As discussed in Chapter IX, regulated power releases will maintain satisfactory water quality until after the year 2020. However, in the absence of such releases, water quality control storage would be needed by the year 2000.

4/ Capitalized at 3 1/8% Federal interest rate for the length of time, 70 years (2000-2070), the project will be needed during the 100-year period of evaluation (1970-2070). Recognition is given here to the advantage of a longer period of service obtainable from a deferred investment as shown by Grant & Ireson. 29/

5/ Discounted from the time of construction (1990).

Alternate #2 - Piping treated municipal and industrial waste flows from the Tulsa area to a point downstream, where streamflow would be adequate to assimilate the treated waste discharges.

Single Unit Construction - (One facility to handle waste discharges through the year 2070) - Estimated life - 50 years

Projected 2070 municipal and industrial waste flows of the Tulsa area would exceed the natural waste assimilative capacity of the Arkansas River near Tulsa by an estimated 148 mgd. Since the bulk of this flow would occur between the months of June and October, temporary holding facilities would be needed to minimize transmission costs. The total cost of a waste flow regulating structure (based on 97,000 acre-feet capacity) including land, low head dam or dike (core type) 1/ fencing, and engineering fees, but excluding cost of transporting wastes to the site is estimated to be $11,808,000. The costs of transporting wastes to the site is excluded since the city must eventually reroute its wastes to a point downstream if use is to be made of the river (near the city) for recreational purposes as planned. 30/ Total annual cost of holding facilities would be $575,000 with $105,000 for operation and maintenance, and $470,000 for amortization at 3 1/8 percent per annum for 50 years. The annual costs 2/ of transporting 148 mgd of waste flow from Tulsa to a point below confluence of the Arkansas and Grand (Neosho) River, a distance of about 45 miles, is estimated to be $2,691,000. 34/

The total estimated annual cost of maintaining water quality in the Arkansas River by this method would therefore be $3,266,000.

Since the original facilities would not be needed until the year 2000 and would require replacement in 50 years, the life of new facilities (installed by 2050) would extend beyond the period of evaluation.

Recognition is therefore given to the project salvage value or the advantage of a longer period of service obtainable from a deferred investment as shown earlier.

On this basis the capitalized value of the annual cost in the year 2000 for a 70-year period 3/ of use (computed at the Federal interest rate of 3 1/8 percent) would be $92,387,000 and have a present (1970) value of $49,927,000.

1/ Costs of "core type" low dam around periphery of storage reservoir based on costs given in the Data Book of Civil Engineering 33/ with revisions to reflect present day prices.

2/ Costs of waste transmission are based on waste water transmission cost curves developed by the Office of Saline Water Conversion 34/ with revisions to reflect present day prices.

3/ Annual costs would be the same after 2050 as before.

Alternative #2 (single unit construction) would therefore have an annual value of $1,636,000 (amortizing at 3 1/8 percent over the 100-year study period, 1970-2070).

Stage Construction - Estimated life - 50 years

Although transmission costs per unit of flow will be substantially higher, some savings would be realized by constructing the waste disposal facilities, discussed above, in stages. By the year 2020 an estimated 32 mgd (average) of wastes from the Tulsa area would need to be dispossed of in the manner under consideration. A small waste flow regulating structure and pipeline would serve the areas need through the year 2020. By the year 2020 a larger facility could be added to handle additional disposal needs (116 mgd estimated for the year 2070) for the next 50 years.

As in the previous case, the first stage facilities would need to be replaced after 50 years and the life of new facilities (installed by 2050) would extend beyond the period of evaluation. Second stage facilities would not be needed before the year 2020 and would therefore have negligible salvage value (based on a 50-year life) by the end of the study period.

Total annual costs of the first stage based on storage facilities with 26,700 acre-feet capacity and transmission facilities capable of handling 32 mgd would be $1,366,000. Total annual costs of the second stage based on storage facilities of 70,400 acre-feet and transmission facilities capable of handling 116 mgd would be $2,682,000. Since this unit would not be needed before the year 2020, it is expected that construction would not be started until the year 2010.

As computed earlier, alternative #2 (stage construction) would have an annual value of $684,000 for the first stage and $474,000 for the second stage or a total annual value of $1,158,000 over the 100-year study period.

Alternate #3 - Providing advanced waste treatment (Tertiary Treatment) for future secondary treated waste discharges. Estimated life - 50 years.

The costs of advanced waste treatment are based on treating that portion (148 mgd) of the city's projected 2070 waste flow which could not be readily assimilated by natural streamflow of the Arkansas River near Tulsa. As in Alternate #2 temporary holding facilities would be needed to minimize costs. Costs of the waste flow regulating structure would be the same as in Alternate #2. Treatment by "adsorption" utilizing granular activated carbon was chosen since it is perhaps the furthest developed of the advanced waste treatment processes and on an over-all basis will increase organic removals from

the 80-90 percent achieved by conventional processes to as much as 97-98 percent. 35/

Cost estimates under Alternate #2 show savings by stage construction. In view of the similarity between Alternates #2 and #3, this method is considered here.

Capital costs for a 10 to 20 mgd adsorption plant have been found to be about 15¢ per daily gallon capacity. 35/ Since cost information is not available for plant sizes of the magnitudes considered here, the above unit cost is used to approximate the costs of waste treatment under Alternate #3.

Stage I - The total annual cost of waste holding facilities (with 26,700 acre-feet capacity) including operation and maintenance and 50-year capital amortization at 3 1/8 percent is estimated to be $202,000. The capital cost of an adsorption plant to handle 32 mgd (assuming 15¢ per daily gallon capacity) would be $4,800,000. Including operation and maintenance and 50-year capital amortization at 3 1/8 percent, the total annual cost of treatment by adsorption would be $671,000. Total annual cost of providing tertiary treatment for Tulsa's waste flows (exceeding the stream assimilative capacity) through the year 2020 would therefore be $873,000.

Since the first stage facilities would not be needed until the year 2000 and would require replacement in 50 years, the life of new facilities (installed by 2050) would extend beyond the period of evaluation.

Recognition is therefore given to the advantage of a longer period of service obtainable from a deferred investment as discussed earlier.

Capitalizing the above total annual cost for the 70-year period of use (during the study period) and spreading the present (1970) value over a 100-year period indicates an annual value for the first stage of Alternative #3 of $437,000.

Stage II - Second stage facilities would not be needed before the year 2020 and would therefore have neglibible salvage value (based on a 50-year life) by the end of the study period.

The total annual cost of waste holding facilities (with 70,400 acre-feet capacity) including operation and maintenance and 50-year capital amortization at 3 1/8 percent is estimated to be $339,000. The capital cost of an adsorption plant to handle 116 mgd (assuming 15¢ per daily gallon capacity) would be $17,400,000. Annual costs of treatment by adsorption would be $2,432,000 giving a total annual cost of additional facilities to be added by 2020 of $2,771,000.

The annual value of Stage II over the 100-year study period and computed as before would be $666,000.

The total annual value of Alternative #3 would, therefore, be $1,103,000.